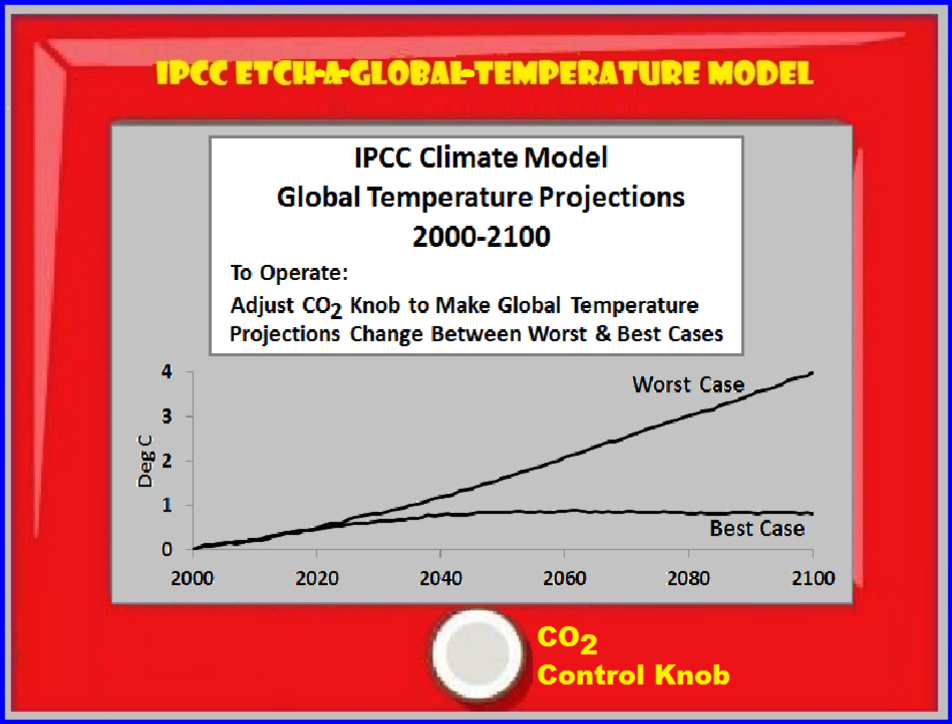
On Global Warming and the Illusion of Control Part 1

Advance Pre-Edit Copy



A Comprehensive Illustrated Introduction to the Hypothesis of Human-Induced Global Warming

By Bob Tisdale

Author of *Who Turned on the Heat?* and *Climate Models Fail*

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This is an early pre-edit copy.

This Table of Contents is interactive. That is, you can fast-forward to a topic by clicking on it.

Table of Contents

PREFACE

The title of this ebook *On Global Warming and the Illusion of Control* is based in part on the theory that was first presented by Dr. Ellen Langer, professor of psychology at Harvard University. Her 1975 paper The Illusion of Control was published in the *Journal of Personality and Social Psychology*. In the abstract of that paper, Langer defined the "illusion of control" as:

> *… an expectancy of a personal success probability inappropriately higher than the objective probability would warrant.*

Let's put that in easier-to-understand terms. The ScienceDaily webpage about illusion of control begins:

> *Illusion of control is the tendency for human beings to believe they can control or at least influence outcomes that they demonstrably have no influence over.*

Illusion of control is appropriate for the current groupthink (more commonly referred to as a consensus) that mankind can control future global temperatures and sea levels and that we can also control climate—control how often weather events occur, how strong they are and how long those events last—simply by limiting carbon dioxide emissions. In other words, the ever-increasing, whimsically optimistic fantasies about modifying and controlling climate through cuts in greenhouse-gas emissions are clear-cut examples of illusion of control.

To fully comprehend this, one needs basic understandings of:

- climate science,
- climate models and,
- even more importantly, the numerous known modes of natural variability.

Those are the three primary topics of this book.

Day in, day out, everywhere we turn—TV, internet, movies, magazines, newspapers—we're bombarded with global warming and climate change propaganda from the mainstream media and in advertisements that proclaim we'll save the Earth if we purchase company *A*'s product, making our world a better place for people four generations in the future.

But you're not buying the hoopla. To you it sounds too hokey—too contrived—like bad science fiction. You may find the climate science community's call for additional research funding undermines their repeated statements that the science is settled. Maybe the ClimateGate emails, which showed climate scientists behaving badly, sparked your skepticism. (See Climategate: The Crutape Letters by Mosher and Fuller published in 2010.) Or, like me, your skepticism may have been prompted by the claims that man-made greenhouse gases are responsible for every weather event.

Sadly, you don't have the time to investigate so you really have no basis for your skepticism.

I found myself in the same predicament more than a decade ago, but I'm a retiree, a pensioner, and I've had time to scrutinize data and climate model outputs. Since then, with years of research into global warming-related data and, as important, the outputs of climate models, I've become a frequent contributor to the world's most-visited website about global warming and climate change WattsUpWithThat.

Maybe you continue to be a firm believer that bad things will happen if global surface temperatures continue to warm beyond a 2-deg C threshold above pre-industrial values…a threshold that was first suggested by an economist, according to Mat Hope & Rosamund Pearce in the article Two degrees: The history of climate change's 'speed limit'. Or maybe you're depressed that the pledges for COP21 will not keep us from passing that threshold of supposed bad things. Or maybe you're simply starting to feel deceived, because governments have been telling us bad things will happen, but they're making no headway at averting those bad things. This book might help you to set aside some of your fears and frustrations. A shift to a skeptical mindset could very well alleviate your concerns.

If you like, think of *On Global Warming and the Illusion of Control* as an exposé written by an investigative reporter with a fluid-dynamics background. Using easy-to-understand terms and lots of illustrations, it reveals the multitude of flaws in the hypothesis of human-induced global warming. Science reporters should have written this book decades ago, but they have apparently become tangled in the politics of global warming.

People can be skeptical of human-induced global warming for many reasons. *On Global Warming and the Illusion of Control* relies on observations-based data and the outputs of climate models. There are no alternate theories presented herein, only data and the outputs of climate models. As you read this book, you should come to understand that the virtual-reality worlds of climate models bear no relation to the world where we live.

This well-illustrated book has been written for persons with little to no knowledge of the hypothesis of human-induced global warming and climate change. It begins with fundamentals, providing answers to basic questions about global warming and climate change. Following that are general discussions of the number-crunched, virtual-reality worlds of climate models. Very basic descriptions of atmospheric and ocean circulation and of modes of natural variability are next. Some of those naturally occurring processes cause major variations in global surface temperatures and precipitation annually. Those same processes, and others, can cause global surfaces to warm for periods of two to three decades or stop that warming for just as long.

A substantial portion of this book is focused on natural variability. It is extremely important and often overlooked in other books about global warming. To help with those discussions, numerous graphs and color-coded maps are presented to show how, where, and when those processes influence global temperatures and other metrics. Of the nearly 450 illustrations in this book, 200+ are dedicated to the basics of atmospheric and ocean circulation and to naturally occurring, naturally fueled ocean-atmosphere processes.

Toward the end of many of the chapters, especially those about modes of natural climate variability, there are discussions of climate models and their failed attempts to simulate those modes. Many of those discussions include simple model-data comparison graphs, and many also include links to scientific papers that expose those climate model failings…and why climate models must be able to simulate those modes of natural variability if they are to have any value.

You'll note that we do spend a good amount of time at the beginning of this book discussing the groupthink aspects of human-induced global warming. It is important to understand those basics if you want to have a basis for your skepticism. From my personal experience, skeptics are different from true-blue believers in human-induced global warming in one important way. Skeptics, like me, understand the proponents' arguments about human-induced global warming. On the other hand, true-blue believers in human-induced global warming will not take the time to understand data-founded arguments that contradict the groupthink. The believers in human-induced global warming simply dismiss any contradictory arguments…even when they are supported by data.

On Global Warming and the Illusion of Control is a prequel to my two more-recent ebooks *Climate Models Fail* and *Who Turned on the Heat? – The Unsuspected Global Warming Culprit: El Niño-Southern Oscillation*. When I started writing this book almost 2 years ago, I had intended to charge a few dollars for it, but I've decided to publish it free of charge in pdf form…with hope that it will have a much-wider circulation and that some readers will find my tip jar and leave a couple of dollars…or purchase the two books linked above. Bottom line: even though the work is copyrighted, feel free to distribute it electronically.

This book should provide readers with enough of a foundation that you will be able to see the hypotheses of human-induced global warming and climate change for what they truly are—computer-aided conjecture—not the incontrovertible science portrayed by politicians, the mainstream media, activist scientists, celebrities, alarmists, and greedy businesspeople cashing in on the latest environmental craze.

Part 2 of this book is about climate-related data: how well metrics like surface temperatures, precipitation and temperatures to the depths of the oceans are actually sampled. The first draft of Part 2 is complete. Unfortunately, there have been many recent changes to a number of datasets, which means I have to revise numerous graphs and rewrite many of the chapters. I'm hoping to finish Part 2 within the next year.

Please don't let the length of the book concern you. While there may be over 700 pages, there are more than 60 chapters…covering topics that are often mentioned in discussions of climate change and global warming. Please jump around to topics that interest you. The Table of Contents above is interactive. That is, you can advance to a topic by clicking on it in the Table of Contents. If you're new to discussions of global warming and climate change, you might want to start with Chapter 1.2 – What is Global Warming? and Chapter 1.5 – What is Climate Change? Maybe you're interested in why global surface temperatures were reported to be at record highs in 2014. Click on General Discussion B - On the Claims of Record High Global Surface Temperatures in 2014. You can also use the word-find feature of Adobe Acrobat for specific topics. Or, in the case of the Introduction, simply scroll through until you find a heading or illustration that interests you. There are more than 400 graphs and color-coded maps in *On Global Warming and the Illusion of Control.*

My sincerest thanks to Anthony Watts, who has published my data-based articles at his blog WattsUpWithThat for more than 7 years. And many more thanks to all those people who offered constructive comments on the threads of the posts at WattsUpWithThat and at my blog ClimateObservations. This book could not have been written without your insights.

In closing to this preface, I truly hope you'll take the time to read and understand what's presented and discussed in this book. The more familiar you are with the basics of the hypothesis of human-induced global warming, the more skeptical you should become that man is the primary cause of global warming and climate change.

INTRODUCTION

Politicians and activist scientists have endeavored to destroy our perception of one of Nature's most humbling, wonder-inspiring rewards: the gift of weather in all its forms…benign and violent. The grandeur of weather is being used by politicians and activist scientists to bludgeon voters and to frighten the gullible.

OVERVIEW OF *ON GLOBAL WARMING AND THE ILLUSION OF CONTROL*

On Global Warming and the Illusion of Control is my latest (and likely last) ebook about human-induced global warming and climate change. The preceding ebooks presented flaws in the hypothesis of man-made global warming and in the climate models that support it, but the discussions were approached from different directions. Those books also assumed readers had fundamental understandings of global warming and climate change. I have not made that assumption with this book.

My goal for *On Global Warming and the Illusion of Control* is to make the discussions and illustrations even more basic, with hope of introducing a new group of people to the numerous flaws in the global warming hypothesis. Data are also presented that contradict claims by alarmists about hurricanes and tropical cyclones, about tornadoes, about floods, about droughts, about weather-related losses in general.

Many people might see climate change and global warming as very complex subjects—suitable only for people with scientific backgrounds. In many respects they are not. This book presents fundamentals in very basic, easy-to-understand terms. There are numerous hyperlinks if you wish to learn more about a certain topic.

In an effort to minimize the complexity, I've limited each chapter to one primary topic. As you've seen in the table of contents, limiting the topics included in a chapter has led to many chapters—taking readers through simple discussions of theory, climate models and ocean-atmosphere processes. Many of the initial chapters provide background information, and as we progress through the book, we'll discuss the many problems with the unquestioning belief that emissions of man-made greenhouse gases are the primary cause of global warming and climate change. Even though chapters are limited to a single topic, some are quite long. Many of those longer chapters are about naturally occurring processes that can and do cause global warming. The reasons for their length: I've presented them in relatively easy-to-understand terms, while still conveying how the naturally driven processes work.

For many persons, their beliefs in man-made global warming or climate change come from the years around 2006 and 2007. Those years coincide with the release of Al Gore's error-filled movie *An Inconvenient Truth* and with the award of the Nobel Peace

Prize to Mr. Gore (a politician) and the Intergovernmental Panel on Climate Change (a political entity).

But much has changed in the eight to nine years since then. The warming of the surface of our planet has slowed to the point where climate models can't explain it, even with the continuous data fiddling. Scientific papers in recent years by experts in specific fields have been exposing the flaws in climate models. And global warming skeptics have become very good at uncovering the faults in those models, in the hypothesis in general and in the datasets that are intended to support them.

BOOKS ABOUT GLOBAL WARMING AND CLIMATE CHANGE

There are hundreds if not thousands of books available on the subject of human-induced global warming. Some are highly technical, written by scientists for scientists. Others are focused at readers without scientific backgrounds. Many of those are filled with alarming prose and images—icebergs birthing, seas destroying shoreline homes, polar bears floating atop small blocks of sea ice—all intended to instill fear of a future filled with extreme weather events and climate catastrophes. Others attempt to counter the alarmist claims. Most present a limited amount of data. *On Global Warming and the Illusion of Control* contains more than 400 hundred color illustrations. This book also contains hundreds of hyperlinks, which are a wonderful feature of ebooks. The links take readers to webpages that provide additional support and more-detailed discussions.

OOPS. GLOBAL SURFACE WARMING DIDN'T ACCELERATE. IT DECELERATED.

Climate scientists around the globe got an unpleasant surprise this millennium. The warming of the surface of our planet slowed considerably. See Figure Intro-1.

When looking at the surface temperature data through more recent years, the climate models did not anticipate the slowdown in the rate of warming.

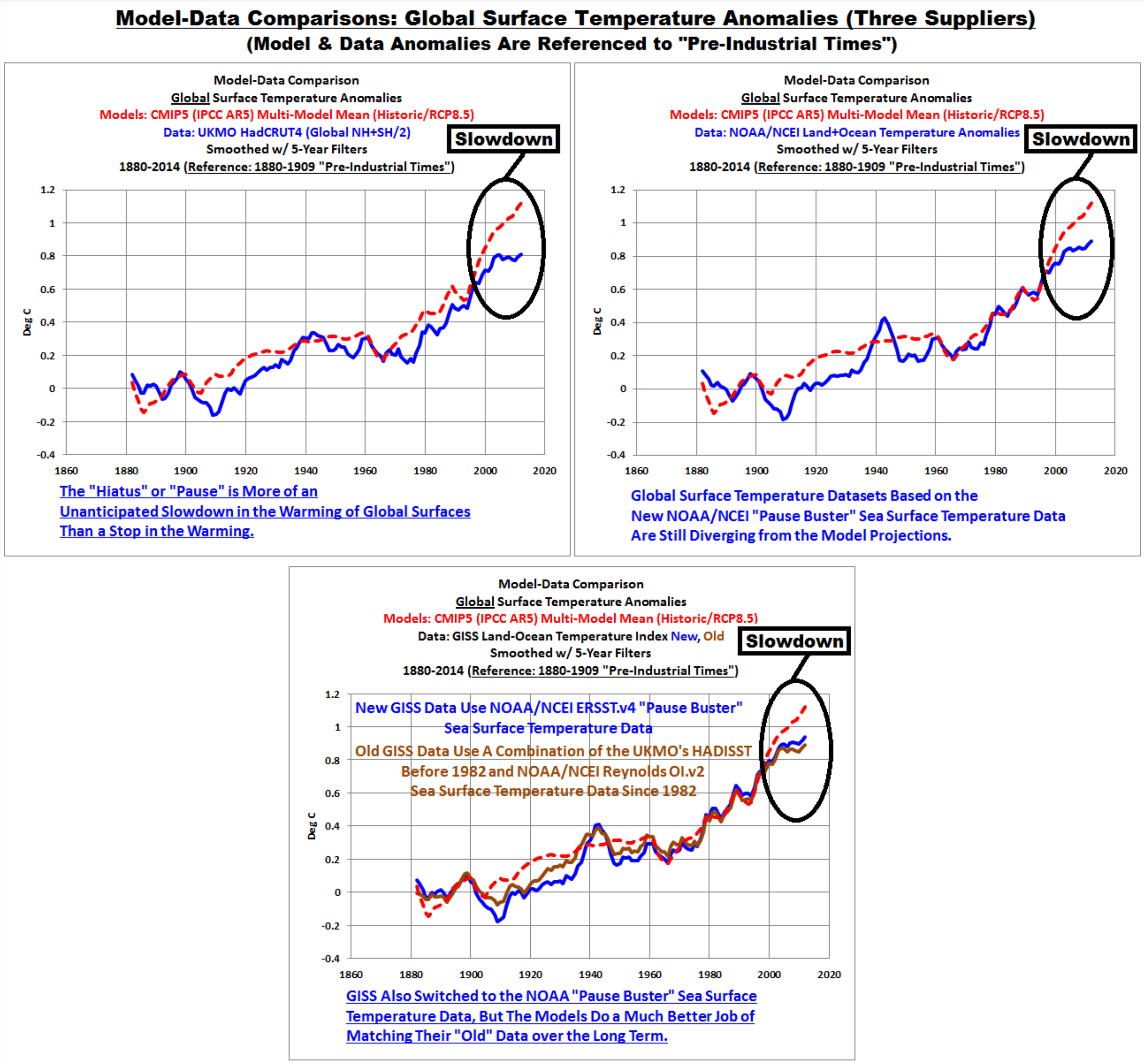


Figure Intro-1

Figure Intro-1 presents model-data comparisons, which include long-term data from the reconstructions of global land+ocean surface temperature anomalies from the 3 primary suppliers. The model outputs and the data have been smoothed with 5-year running-average filters to reduce the year-to-year volatility.

The data are the products of:

- the UK Met Office, a.k.a. UKMO (upper left-hand, data available here);
- the NOAA National Centers for Environmental Information, a.k.a. NCEI (upper right-hand, data available here); and
- the NASA Goddard Institute of Space Studies, a.k.a. GISS (bottom, data available here).

The current versions of the data from 1880 to 2014 (blues curves) are compared to the average of the simulations of global surface temperatures (red dotted curves) from the climate model outputs stored an archive called the Coupled Model Intercomparison Project, Phase 5 (CMIP5). The models from the CMIP5 archive were used by the Intergovernmental Panel on Climate Change (IPCC) for their 5th Assessment Report (AR5), and the outputs of the models are available through the KNMI Climate Explorer, a wonderful web tool. We're presenting the average of the climate model outputs, known as the model mean, because it represents the consensus (better said, the groupthink) of how global surfaces should have warmed, if they were warmed by the factors (primarily man-made greenhouse gases) that drive the models. (The use of the model mean is discussed in more detail in Chapter 2.11 – Different Ways to Present Climate Model Outputs in Time-Series Graphs: The Pros, the Cons and the Smoke and Mirrors.)

Climate alarmist websites like SkepticalScience have recently started to present long-term global surface temperature anomaly data with the anomalies referenced to a "pre-industrial period". See the SkepticalScience post Tracking the 2C Limit, August 2015, by Rob Honeycutt. The intent is to show that global surface temperatures are at or near to the halfway point of the 2 deg C threshold that politicians focus on in their efforts to limit global warming. So I've gone along with the new fad in Figure Intro-1, using the averages of the period of 1880-1909 as the references for anomalies.

Note: Pre-industrial typically refers to the period of 1750 to 1850, but the data from GISS and NCEI start in 1880. So we're using the first 30-year period as the base years. [End note.]

As shown in Figure Intro-1, the slowdown is more pronounced in the UK Met Office (UKMO) data. The land+ocean products from the NOAA National Centers for Environmental Information (NCEI) and the NASA Goddard Institute for Space Studies (GISS) include NOAA's new "pause-buster" sea surface temperature data. Even with the new much-manipulated sea surface temperature data, the models are showing too much warming.

You'll note that I've included a second "old" version of the GISS reconstruction in that model-data comparison (bottom graph in Figure Intro-1). GISS does not produce the sea surface temperature dataset they use in their Land-Ocean Temperature Index. They rely on others for that critical portion. Keep in mind, the oceans cover about 70% of Earth's surface.

GISS has switched sea surface temperature datasets twice since early 2013. Let's take a closer look at the subtle impacts of those changes.

THE THREE FACES OF THE GISS LAND-OCEAN TEMPERATURE INDEX

I've presented all three versions of the Goddard Institute for Space Studies (GISS) Land-Ocean Temperature Index (LOTI) in Figure Intro-2. We're using the same base years, same model mean, and the same 5-year smoothing as Figure Intro-1. GISS still presents their older and interim versions at their website, assumedly for researchers who prefer the different sea surface temperature products. See the "Ocean" dropdown menu on the GISS map-making webpage and the Compressed files at the bottom of their webpage linked above.

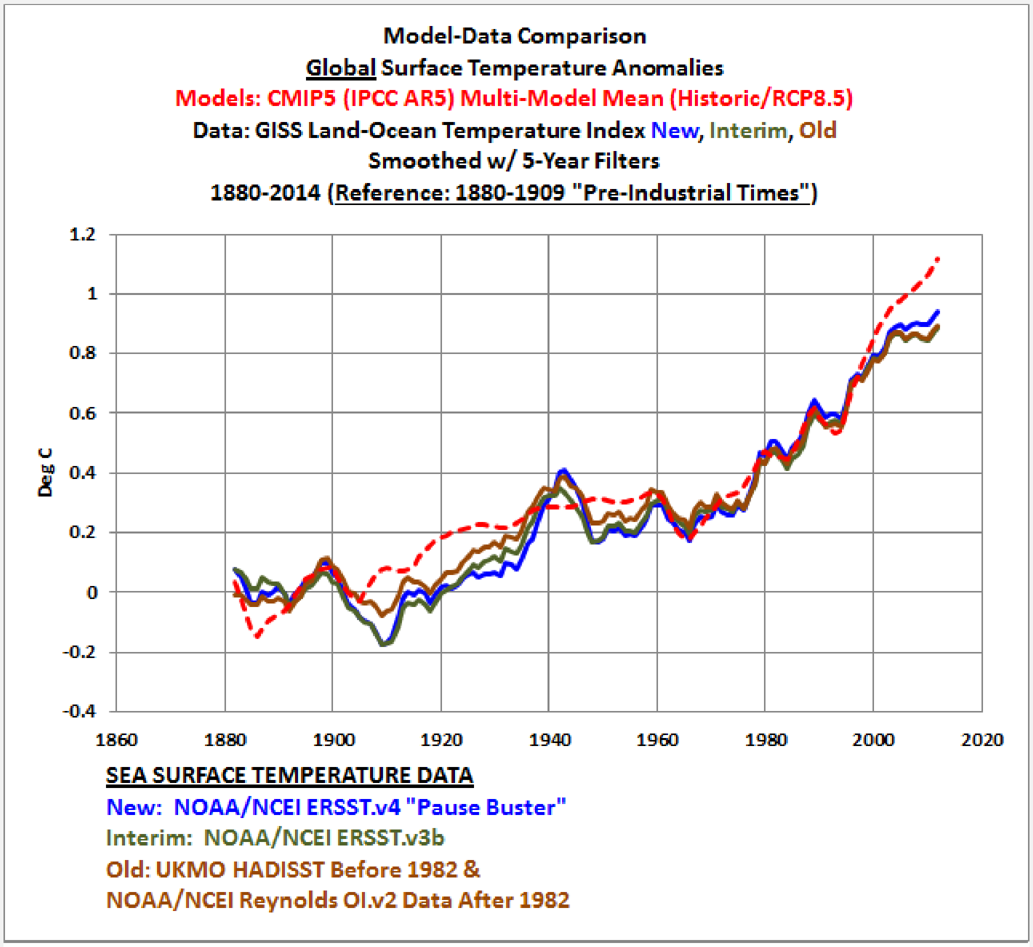


Figure Intro-2

In addition to the land surface air temperature data from meteorological stations, the "old" version of GISS LOTI (brown curve) used a combination of two sea surface temperature products: UKMO HADISST from 1880 to 1981 and NOAA's satellite-enhanced optimum-interpolated sea surface temperature data (commonly referred to as Reynolds OI.v2) from 1982 to present. See Hansen et al. (2010) Global Surface Temperature Change. GISS used that combination of sea surface temperature data in their official product until December 2012. Starting with their January 2013 update, GISS then switched to the ERSST.v3b sea surface temperature reconstruction from NOAA/NCEI. I've called that version the "interim" data in Figure Intro-2 (dark green curve). GISS switched sea surface temperature datasets once again in July 2015, now to the NOAA/NCEI ERSST.v4 sea surface temperature reconstruction, referred to as NOAA's "pause-buster" data throughout this text. That's the "new" data in Figure Intro-2 (blue curve). See the GISS Updates to Analysis webpage to confirm those changes. (We'll discuss how NOAA "overcooked" the "pause-buster" data later in this Introduction, and in more detail in Part 2 of this book.)

GISS has made numerous other subtle changes to the land portion, but the biggest (obvious) changes occurred when they switched sea surface temperature data. When GISS swapped from the "old" to the "interim" sea surface temperature data, they increased the difference between the models and data from the early 1900s to about 1960. Note how much more the "interim" data drops than the "old" data from 1900 to 1910. Not only did that increase the perception of warming from 1900 to current times, but it also increased the warming rate of the data from about 1910 to the early 1940s…well beyond the warming shown by the models during that early warming period. And as you can see, the swap from "old" to interim" had little impact after 1997, with the two curves overlapping in recent times.

The switch to the NOAA ERSST.v4 "pause-buster" sea surface temperature data did not help the model-data difference from early 1900s to about 1960, but it did impact the GISS Land-Ocean Temperature Index (LOTI) data since 1997. Unfortunately for the models, they still show too much warming in recent years.

1997 and 2001 have been commonly used as the start years of the slowdown in global warming. Let's use another simple method to confirm that the models still simulate too much warming.

We'll use maps that display the change in surface temperatures based on linear trends, from 1997 to 2014 and from 2001 to 2014, Figure Intro-3. We can see that some portions of the globe have actually cooled, not warmed as shown by the climate models, during what is now being called "the pause" in global warming. (Maps of global temperature anomalies and trends like those shown in Figure Intro-3 are available through the KNMI Climate Explorer.)

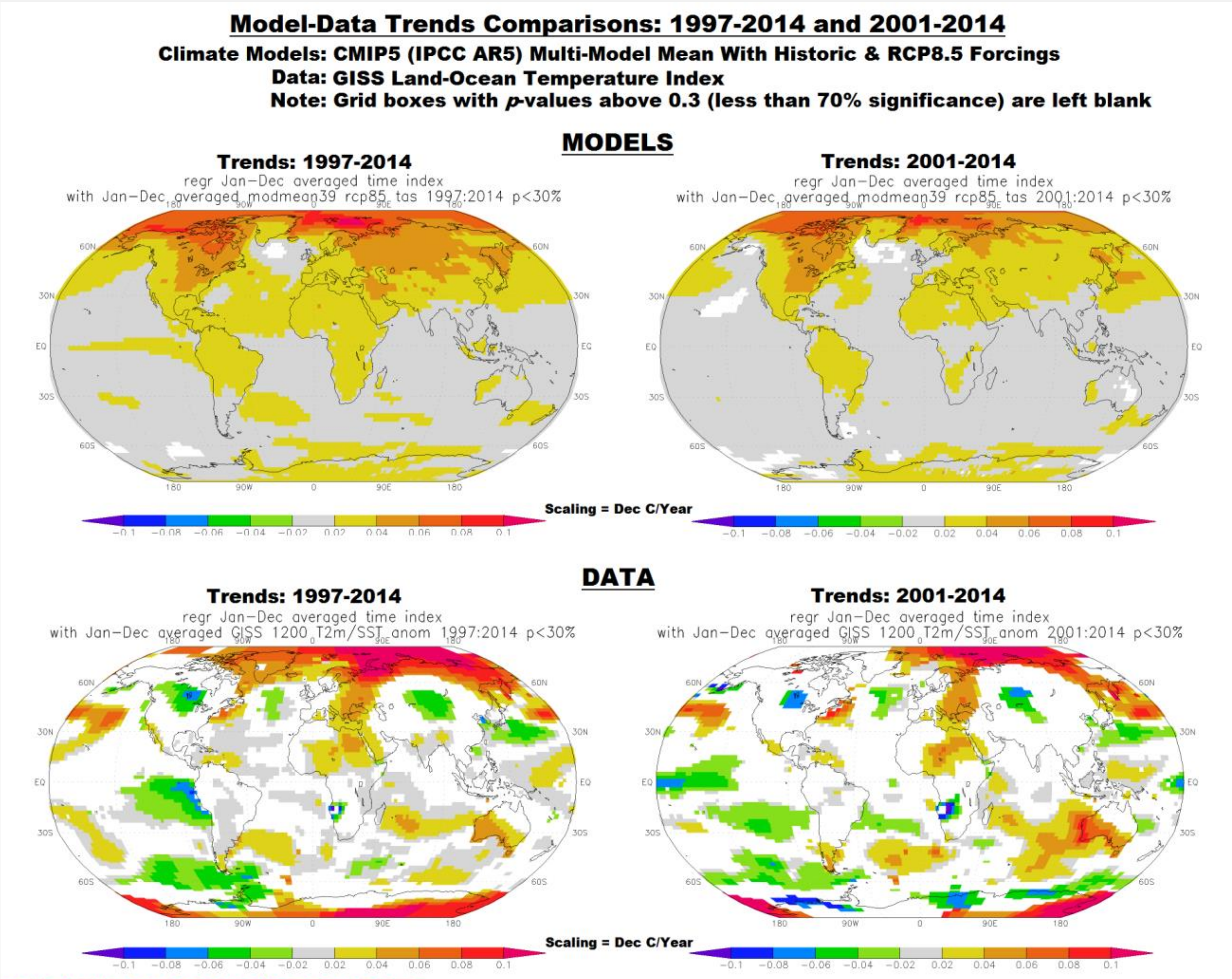


Figure Intro-3

That is, the models underestimated the observed warming regionally near the North and South Poles, but grossly overestimated it almost everywhere else. And the models definitely don't show the regional cooling that's visible around the globe.

The naturally caused warming event in the North Pacific (called *The Blob*) and the 2015/16 El Niño (also natural) have already had an impact on the slowdown. Even so, the models are still showing way too much warming. (See General Discussions B and C.)

THE RESPONSE OF THE CLIMATE SCIENCE COMMUNITY TO THE DIVERGENCE BETWEEN MODELS AND REALITY

Initially, in the late-2000s, climate scientists downplayed the slowdown. As the slowdown continued, they tried to redirect the discussion, saying carbon dioxide was still causing global warming, but the heat was hiding deep in the oceans…but, as we'll see in a few moments, even the ocean temperatures to depths of 2000 meters (about

1.25 miles) are not cooperating with the hypothetical impacts of global warming. In more recent years, the slowdown had lasted long enough that new studies were appearing monthly and in them scientists are proposing new theories—dozens of new excuses—for where the climate-model-predicted man-made heat was going. All of those studies, whether they intended to or not, highlighted how little is actually known about the cause of the warming from the mid-1970s to the turn of the century. If they couldn't agree on an explanation for the slowdown, they had little understanding of the warming.

Recently, the National Oceanic and Atmospheric Administration (NOAA) revised their surface temperature data for the global oceans (known as sea surface temperature data) so that the data show more warming during the "hiatus". That new data has been nicknamed "pause-buster". Not too surprisingly, when compared to the dataset NOAA used as a reference for "bias adjustments", we discover that NOAA overcooked their adjustments. (More on that in a few moments.)

Data are supposed to portray the realities of climate. Not too surprisingly, the constant manipulations of temperature-related data of the past couple of decades always seem to warm the more recent observations or cool the data from a few decades ago…or both. Cooling the past and warming the present both work to increase the warming rate during the slowdown. Many persons began to see that every "fix" created warming and they understood the odds of that was very unlikely, but that's what was happening…and still going on. Apparently, the realities of climate (the data) are subject to change at the whims of government agencies.

As noted above, NOAA and GISS recently revised their global surface temperature reconstructions, with the biggest changes occurring in the sea surface temperature portion. One the obvious intents was to disappear the slowdown in global surface warming that has been taking place for almost 2 decades. The paper that supports the new data is Karl et al. (2015) Possible artifacts of data biases in the recent global surface warming hiatus. Based on the title, the obvious focus of NOAA's data adjustments was the recent slowdown in global warming. But also note the first word in the title…"Possible"…which indicates the uncertainty in their findings.

One of the humorous aspects of Karl et al. (2015) was their attempt at misdirection. Specifically, after the data manipulation, they claimed the warming rate during the "hiatus" was similar to the long-term warming trend since 1950…thus no "hiatus". But what they failed to acknowledge was climate models still showed a much higher warming rate, that their tweaking did not erase the still-growing difference between models and their much-manipulated data.

NOAA used a marine air temperature dataset (a dataset that's inferior due to the much lower number of temperature samples) from the UK Met Office as a reference for their new sea surface temperature adjustments. That is, NOAA manipulated the sea surface temperature data so that their long-term warming curve mimicked the marine air temperature data. But a look at the short-term data in recent years showed something unusual. A comparison of the new NOAA "pause-buster" data and the reference data since 1998 (Figure Intro-4) reveals that NOAA over-adjusted the sea surface temperature data so that they have a higher warming rate than the reference data. Thus my comment that NOAA overcooked the adjustments. We'll spend more time on that topic in the upcoming Part 2 of this book.

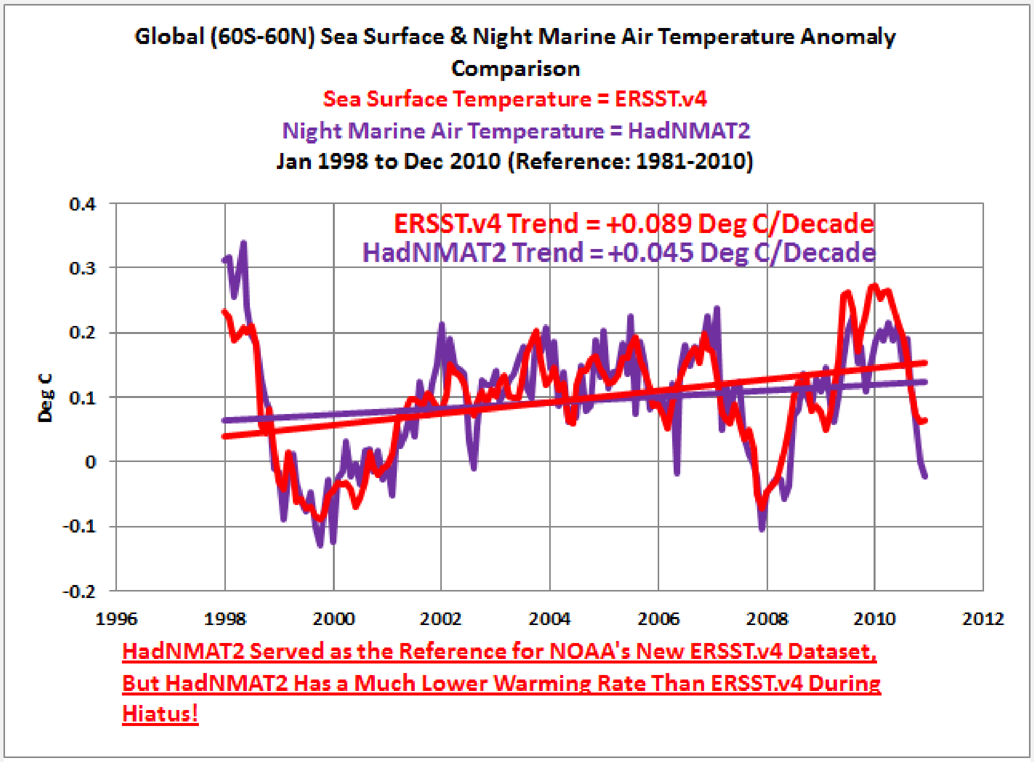


Figure Intro-4

Referring to Figure Intro-5 (below), the pause (also known as "the hiatus", "the lull", "the plateau", etc.) is more prevalent in the satellite-based datasets that represent the temperature of the atmospheric layer closest to Earth's surface—what is called the lower troposphere. In fact, the similarities between the warming rates of the surface temperature products and the lower troposphere products from 1979 to 2001—and their blatantly obvious disagreement after 2001—lead many people to conclude the surface temperature products in recent years have been manipulated too much, creating an unrealistic warming.

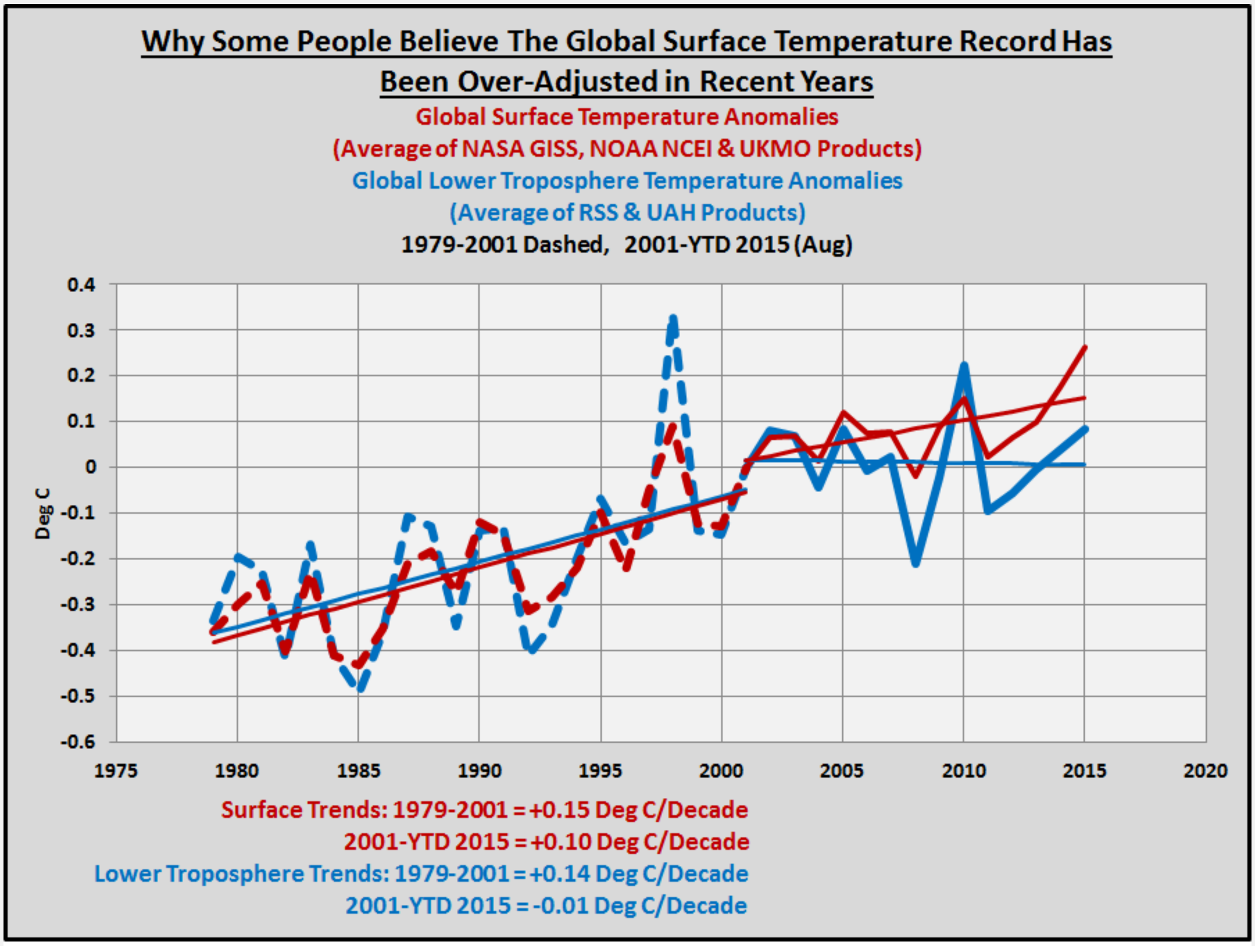


Figure Intro-5

AN IMPORTANT NOTE ABOUT MODEL-DATA COMPARISONS

There are numerous model-data comparisons provided in this book, but consider something very important: only two of the modeling groups have documented how and over what time period they've tuned their models. That lack of documentation creates a major problem…we do not know if we're examining (1) the characteristics of the models or (2) the tuning efforts of the modelers. In either case, most of the results are not good, as you shall see. [End note.]

EXAMPLES OF CLIMATE MODEL PERFORMANCE…OR LACK THEREOF

The pause suggested to some curious onlookers that the man-made global warming hypothesis was just another in a series of unfounded scares. As a result of the pause, independent climate researchers began investigating climate model performance, and they discovered those virtual representations of climate on Earth had mixed results (mostly bad) in their attempts to simulate surface temperatures, precipitation, and sea ice. Let's look at a few quick examples of those failings, which I've been showing for a number of years. We'll start with the mixed results.

Over the past 3+ decades, climate models do a reasonable job of simulating the observed warming rate of the air measured on land surfaces at weather stations, as shown in Figure Intro-6.

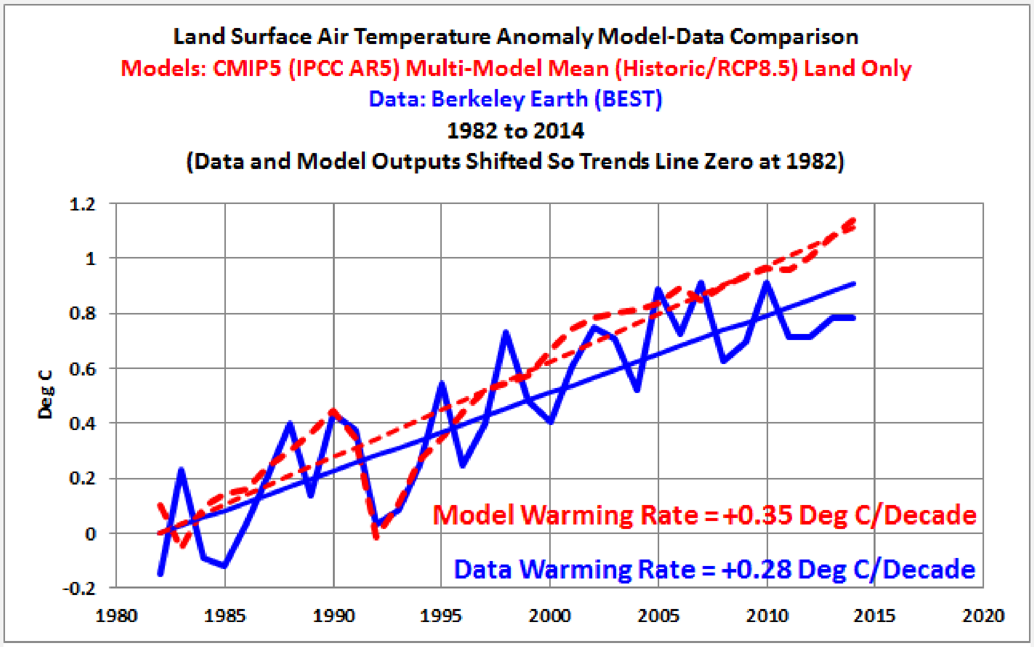
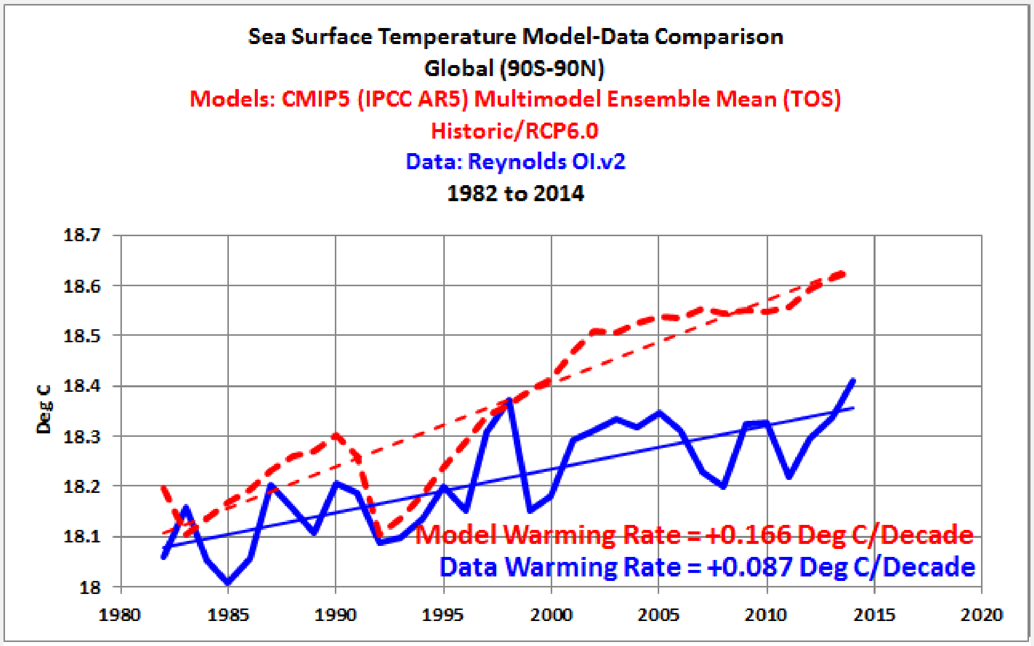


Figure Intro-6

But, as shown in Figure Intro-7, they double the warming rate of the satellite-enhanced observations of global sea surfaces. The data shown in Figure Intro-7 is known as Reynolds OI.v2. It is also a product of NOAA, but they do not include it in their global land+ocean surface temperature product because this better dataset doesn't show as much warming as their dataset that's based only on data from ship inlets and buoys. How much better is this satellite-enhanced sea surface temperature dataset? The authors of the 2004 Smith and Reynolds paper Improved Extended Reconstruction of SST (1854-1997) called the Reynolds OI.v2 data "a good estimate of the truth." (For a further discussion of the advantages of the Reynolds OI.v2 sea surface temperature data, see General Discussions B and C, under the heading of INFO ABOUT THE SEA SURFACE TEMPERATURE DATASET.)



Climate Models Almost Double The Observed Warming Rate Of The Global Ocean Surfaces. Climate Scientists Are Also Still Looking For About 50% Of The Heat That Is Supposed To Be Stored In The Oceans. The "Missing Heat" And Doubling Of Ocean-Surface Warming Suggest The Model Sensitivities Are At Least Two-Times Too High.

Figure Intro-7

Now, recall that the oceans cover about 70% of the surface of the planet and you'll come to understand the impact of the model failing shown in Figure Intro-7. Also we have to consider the fact that the warming of the ocean surfaces is one of the primary reasons for the warming of the air above land surfaces. (See Compo and Sardeshmukh (2009) **Oceanic influences on recent continental warming**.) That also places in question the better modeling of the warming of the air above land surfaces (Figure Intro-6). That is, how can the modelers better simulate the warming of the air above land surfaces, when they are so far off with sea surfaces, which are a major contributor to the warming of the air immediately above land surfaces?

Also as a quick introduction to climate model failings, we'll look at sea ice. It is well known that climate models can't simulate the rate at which sea ice has been lost in the Arctic. The models do not simulate Arctic sea ice losses fast enough. See Figure Intro-8. Oddly, alarmists happily point out this climate model failing with claims that Arctic sea ice loss is "worse than predicted".

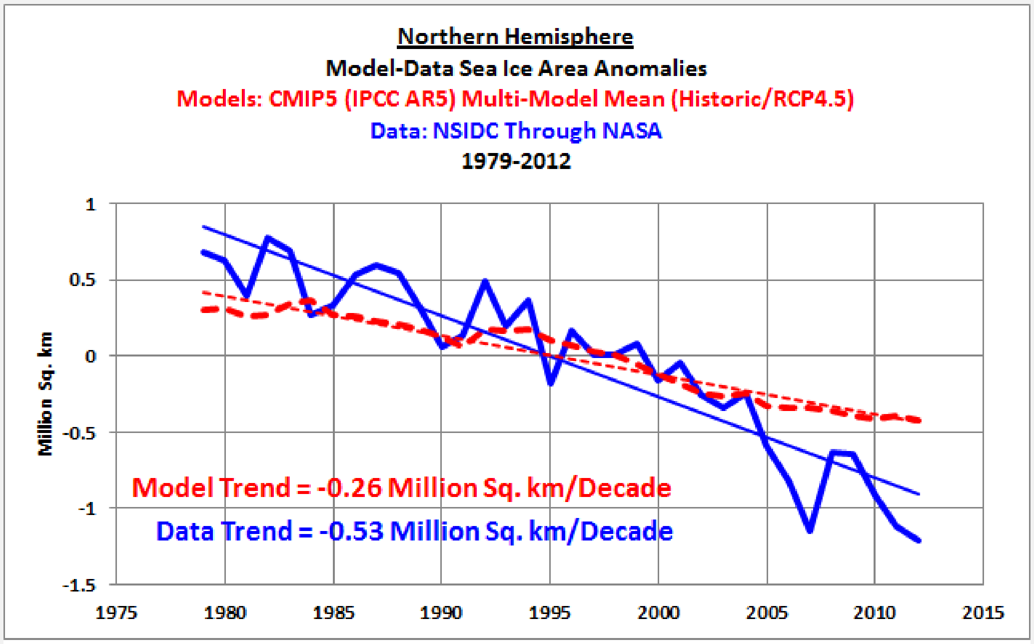


Figure Intro-8

At the other end of the globe, in the Southern Ocean surrounding Antarctica, climate models show a loss of sea ice, but, contradicting the models, data indicate sea ice extent and area have grown there over the past 35+ years, as shown below in Figure Intro-9.

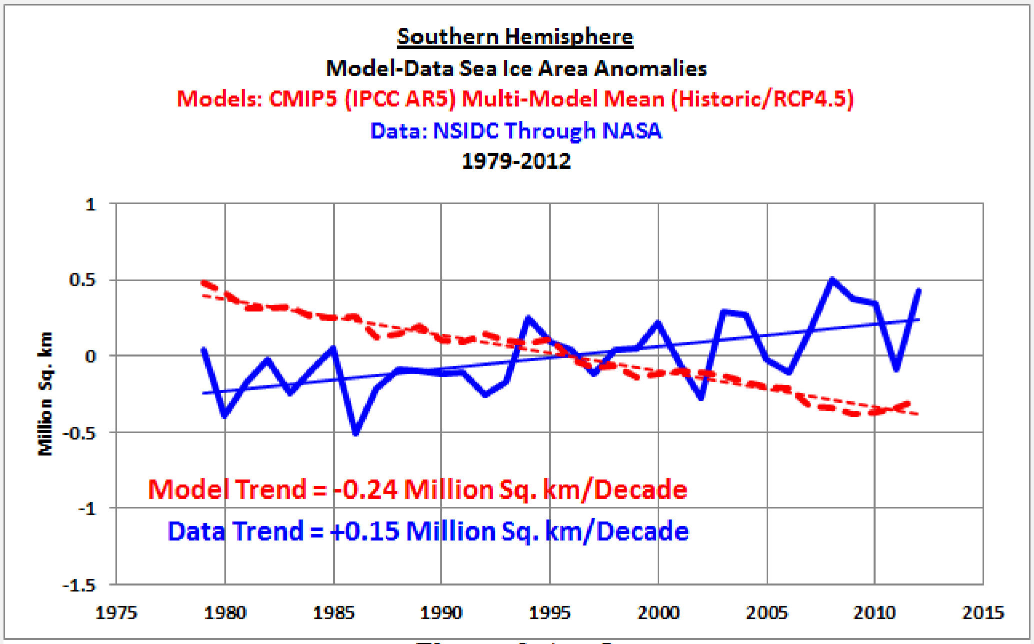


Figure Intro-9

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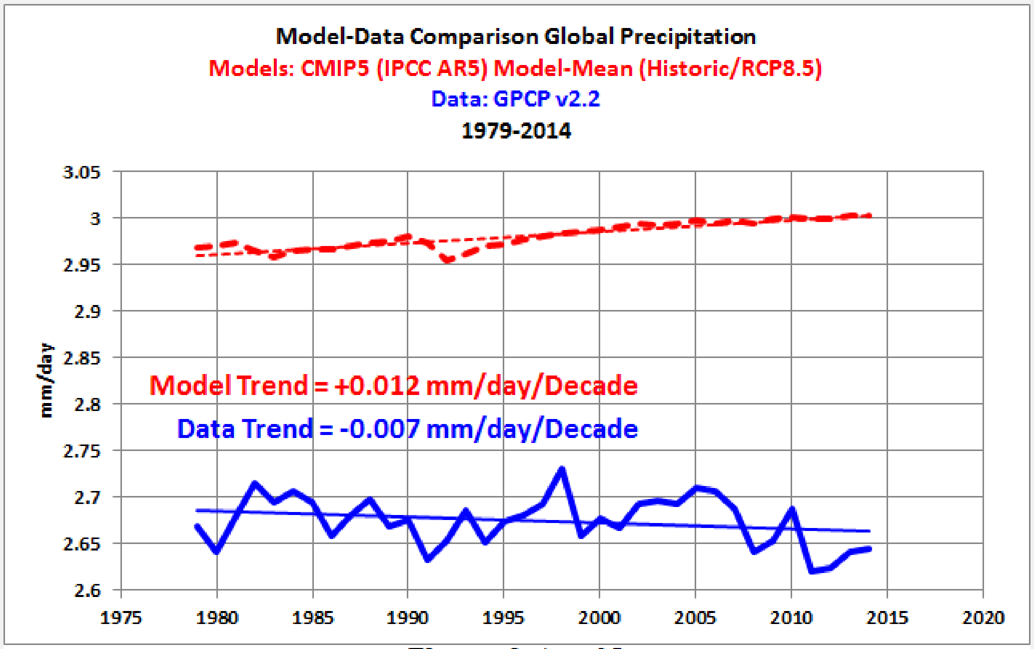


Figure Intro-10

Then there's precipitation. A model-data comparison for global precipitation is provided in Figure Intro-10. The difference in trends doesn't appear very noteworthy. The models show we should have seen a slight increase in global precipitation since 1979 (about +1.4% based on the linear trend), but the satellite- and rain gauge-based data (GPCP v2.2 from NOAA) show a slight decrease (about -0.9% based on the linear trend) over the past 35 years. The biggest disparity, however, is in the amount of precipitation shown in the models. The average of the models (the consensus, a.k.a. groupthink) are generating more than 10% too much precipitation. That might not sound like a lot, but, according to the modeled worst-case scenario, global precipitation is only supposed to increase about 7% by the end of the 21st Century. In other words, the difference between the modeled and observed global precipitation in recent decades is greater than the expected worst-case increase by 2100.

Figure Intro-10 also suggests something else: there may be too much water vapor in the climate models' virtual atmospheres. Water vapor is a greenhouse gas. The higher the water vapor, the greater the warming in the models.

So the pause wasn't the only problem with the models that support the hypothesis of human-induced global warming. There are numerous other flaws with the climate model-dependent hypothesis, clearly indicating model capabilities have been oversold.

MISSING HEAT

Some climate scientists now claim the "missing heat" must be hiding deep in the oceans, because the oceans have an extremely high capacity to store heat. Once again, temperature measurements contradict speculation.

Reasonably complete temperature samples of all the ice-free oceans to the depths of 2000 meters (about 6600 feet or about 1.25 miles) have only been available for the past decade or so. Those new sensors were deployed as part of the ARGO program in the early 2000s and did not have complete coverage of the oceans until about 2003. The U.S. National Oceanographic Data Center (NODC) uses those temperature samples for a number of datasets, including their vertically averaged temperature data for the depths of 0 to 2000 meters.

Many climate studies have called into question the usefulness of the temperature measurements of the deep ocean before ARGO. That is, they use only the ARGO-era data when discussing the warming of the oceans at depths of 0-2000 meters, because the data are so sparse before 2003.

As shown in Figure Intro-11, the ARGO-era temperature data for those depths show the South Atlantic and Indian Oceans have warmed, while the North Atlantic and the largest ocean on our planet, the Pacific, show very little warming over the past 12 years.

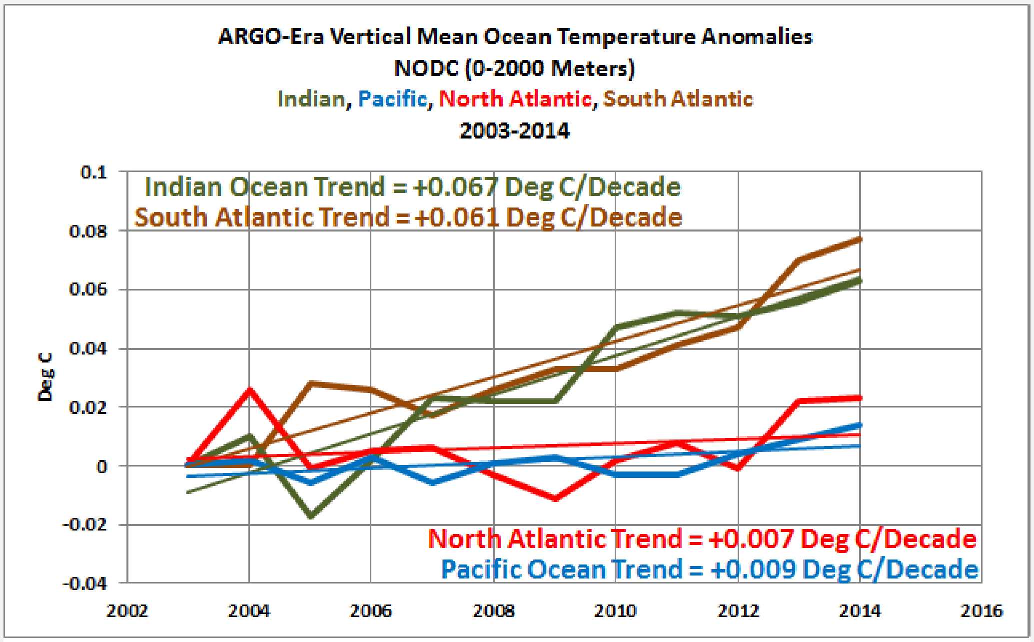
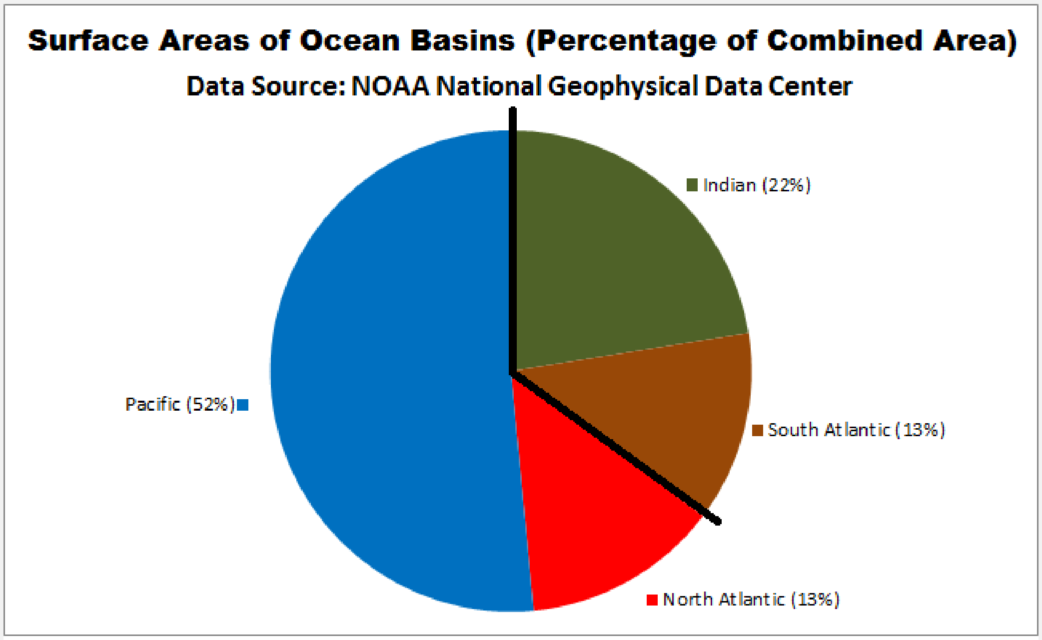


Figure Intro-11

# # #



Since 2003, the Indian and South Atlantic Oceans Have Warmed to Depths of 2000 Meters, While the Pacific and North Atlantic Have Warmed Little.

Figure Intro-12

The pie chart in Figure Intro-12 helps to put that in perspective. It illustrates the surface areas of the Indian, South Atlantic, North Atlantic and Pacific as percentages of their total surface area. (Source of the surface areas is here.) The North Atlantic and Pacific Oceans cover almost two-thirds of those oceans and they have warmed very little in 12 years to depths of about 2 kilometers (1.25 miles). Now look again at the graph in Figure Intro-11 above, this time concentrating on the scale of the vertical axis (y-axis) and on the listed warming rates. For the two ocean basins that have warmed, the warming rates are measured in one-hundredths of a deg C/decade, while for the North Atlantic and Pacific, the trends are in one-thousandths of a deg C/decade.

Something else to consider: the raw, unadjusted ARGO-based temperature data show that oceans have warmed at a much slower rate. That is, the data have to be adjusted (altered, modified, reworked, tweaked, manipulated) to show the minimal warming rates shown above in Figure Intro-11. The impacts of those adjustments can be seen in the comparison of the adjusted and unadjusted global ocean heat content data for the depths of 0-2000 meters in Figure Intro-13. The adjustments triple the observed warming rate (2005-2013) of the global oceans to the depths of about 1.25 miles (2 kilometers). Triple.

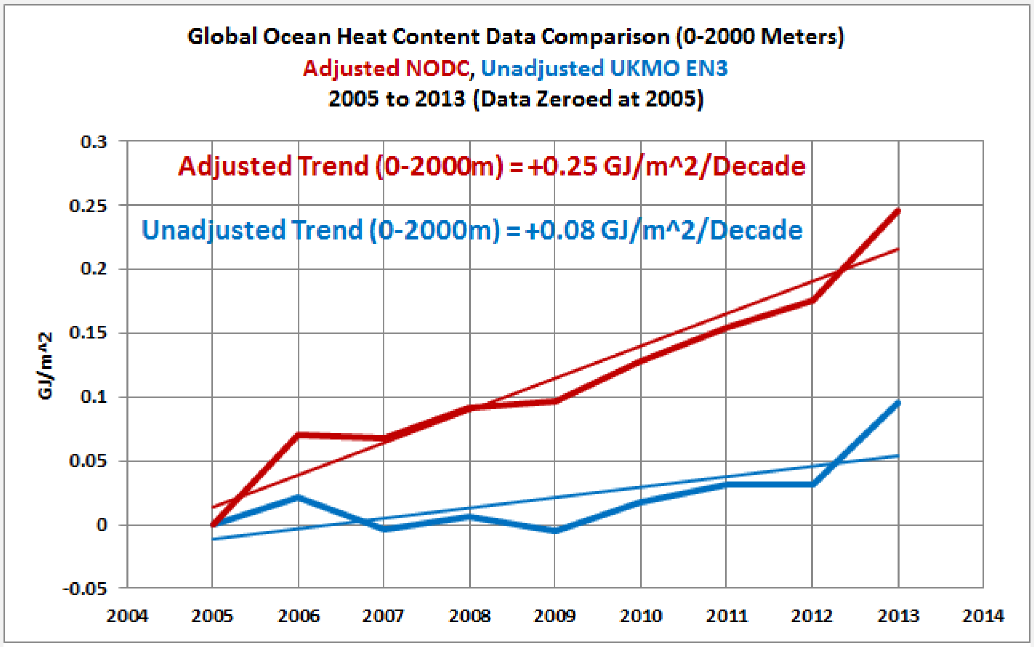
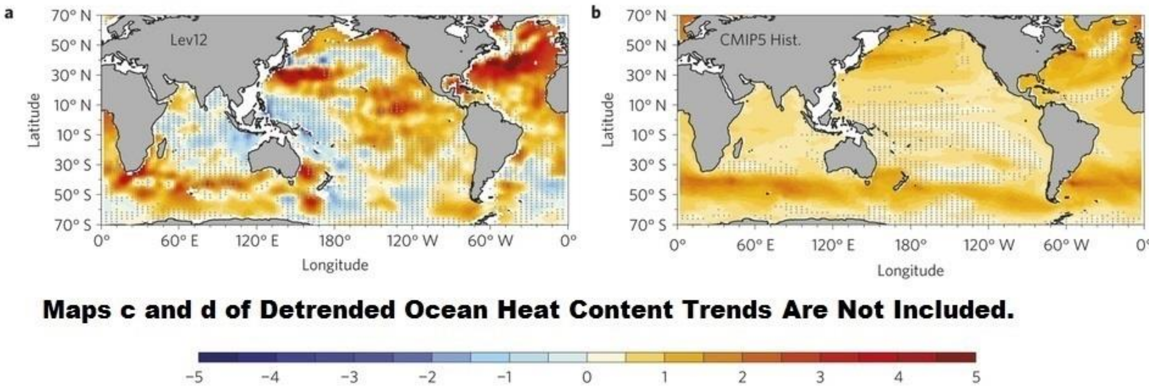


Figure Intro-13

Another problem for the climate science community: I had provided an explanation for the difference in the warming rates between the Indian and Pacific Oceans a number of years ago. See the discussion of Figures 19 and 20 and Animations 1 and 2 in the post Is Ocean Heat Content Data All It's Stacked Up To Be? A recent paper by Lee et al (2015) confirmed my discussion of the transfer of El Niño-related waters from the tropical Pacific to the Indian Ocean. But because man-made greenhouse gases are said to be evenly mixed, the multi-model mean of the climate models used by the IPCC (for attribution studies and projections of future climate) show a relatively uniform warming of the oceans, the right-hand map in Figure Intro-14. Yet in the real world that is not the case, as shown in the left-hand map. Those maps are from Durach et al. (2014) Quantifying underestimates of long-term upper-ocean warming. Notice that it covers the period of 1970-2004. It's rare when climate modelers provide side-by-side maps of modeled and observed ocean heat content trends, so rare that I have not been able to find maps comparing models and data for the deep ocean during the ARGO era. (Quick note, the multi-model mean basically represents how the oceans should have warmed if they were warmed by man-made greenhouse gases.) Putting the lack of an ARGO-era comparison aside, it's difficult at best, therefore, to imagine how climate modelers would attempt to explain how man-made greenhouse gases could be warming one-third of the oceans to depths of more than a mile but not the other two-thirds, when their models have a history of showing a more uniform warming.

Abridged Figure 1 from Durack et al (2014)

Observed (a) and Multi-Model Mean Simulations (CMIP5) (b) of Upper-ocean (0–700 dbar) heat content trends for 1970–2004.



a,**c**, Observations taken from Lev12 (ref. 11). **b**,**d**, MMM results taken from CMIP5 historical simulations. Lower panels (**c**,**d**) show maps with the global average trends removed. All trends are reported in units of $J \times 10^3\ kg^{-1}\ 35\ yr^{-1}$ (a value of 4 being approximately equivalent to 1 °C 35 yr^{-1} depth-averaged warming). Stippling marks regions where the four observational estimates do not agree in sign (**a**,**c**) or where >25% of the models simulate trends with a sign opposite to the MMM (**b**,**d**).

Figure Intro-14

Notes: The paper Lee et al. (2015) overlooked something critical…something else that's discussed later in this book: the warm water that serves as fuel for El Niño events is furnished by sunlight. Lee et al also did not address the lack of warming to depth in the North Atlantic shown in Figure Intro-11. [End notes.]

TOO MUCH FAITH IN CLIMATE MODELS

Climate models are not evidence, yet they are treated as if they are. The science behind the global warming movement has become a model-based science. While data do indicate that Earth's atmosphere and oceans had warmed, and while data do show that carbon dioxide levels in the atmosphere have increased due to the burning of fossil fuels, all of that data do not provide any evidence the rising concentrations of carbon dioxide caused a measureable portion of the warming. The theoretical effects of increased concentrations of greenhouse gases are well known, but what is unknown is the extent to which natural processes exaggerate the warming effects (with positive feedback) or counteract them (with negative feedback). Climate scientists must rely on numerical models of the atmosphere and oceans—virtual climate—in order to attribute global warming to man-made greenhouse gases.

Unfortunately, the models perform extremely poorly in their simulations of the atmosphere and oceans (see Figures Intro-6 through Intro-12 above)…so poorly, the only evidence the models furnish is that they do not properly simulate Earth's climate.

Relying on climate models as they exist today for the study of global warming and climate change would be similar to physicians having to rely on computer models of the human body that cannot simulate respiration, digestion, circulation, etc.

Climate models do not provide evidence that increased emissions of CO_2 cause global warming and climate change. Climate models only display the programming skills of the climate modelers…based on the multitude of undocumented assumptions those modelers have made. Were you aware that only two of the dozens of climate-modeling groups have documented in scientific papers how they tune their models?

I'm going to repeat the first sentence of the last paragraph: Climate models do not provide evidence that increased emissions of CO_2 cause global warming and climate change; the models only suggest there is a possible connection. Many people have lost track of the state of the climate science and the models that support it. Those persons are treating climate models as if they provide proof, when, in fact, the models are nothing more than very expensive computer-aided conjecture.

The Australia Academy of Science confirms this naïve belief in climate models on their Summary webpage about The Science of Climate Change (my boldface):

> *Climate models allow us to understand the causes of past climate changes, and to project climate change into the future. Together with physical principles and knowledge of past variations,* ***models provide compelling evidence that recent changes are due to increased greenhouse gas concentrations in the atmosphere****. They tell us that, unless greenhouse gas emissions are reduced greatly and greenhouse gas concentrations are stabilised, greenhouse warming will continue to increase.*

Realistically, the only evidence provided by climate models is that they have been programmed so that the numerical representations of greenhouse gases impact the simulated numerical climate in the models. Nothing more.

Climate scientists use those models—that cannot simulate Earth's climate as it has existed at any time in the past—to foresee what climate might be like in the future, not what climate will be like in the future. And those future climates depend on a number of prognostications (scenarios) of future population and economic growth, land use, greenhouse gas emissions, etc. All of the projections of future climate assume that Earth's climate is similar to those in the models, but climate scientists know very well that their models are far from reality. Unfortunately, the general public has not been informed of those uncertainties and what they mean. And because the public doesn't understand climate models and their failings, politicians are taking advantage of that lack of knowledge.

Dr. Richard Lindzen is an Alfred P. Sloan Professor of Meteorology (emeritus) at the Massachusetts Institute of Technology, and he's also a long-time critic of climate models and of global warming leading to catastrophes. An April, 2014 presentation to the European Institute for Climate and Energy (EIKE) by Dr. Lindzen can be found on YouTube here. Early in the presentation, Dr. Lindzen states:

> *…it should be recognized that the basis for a climate that is highly sensitive to added greenhouse gasses is solely the computer models. The relation of this sensitivity to catastrophe, moreover, does not even emerge from the models, but rather from the fervid imagination of climate activists.*

As you progress through this book, you'll find data-based evidence that confirm Dr. Lindzen's statements. Here's an example:

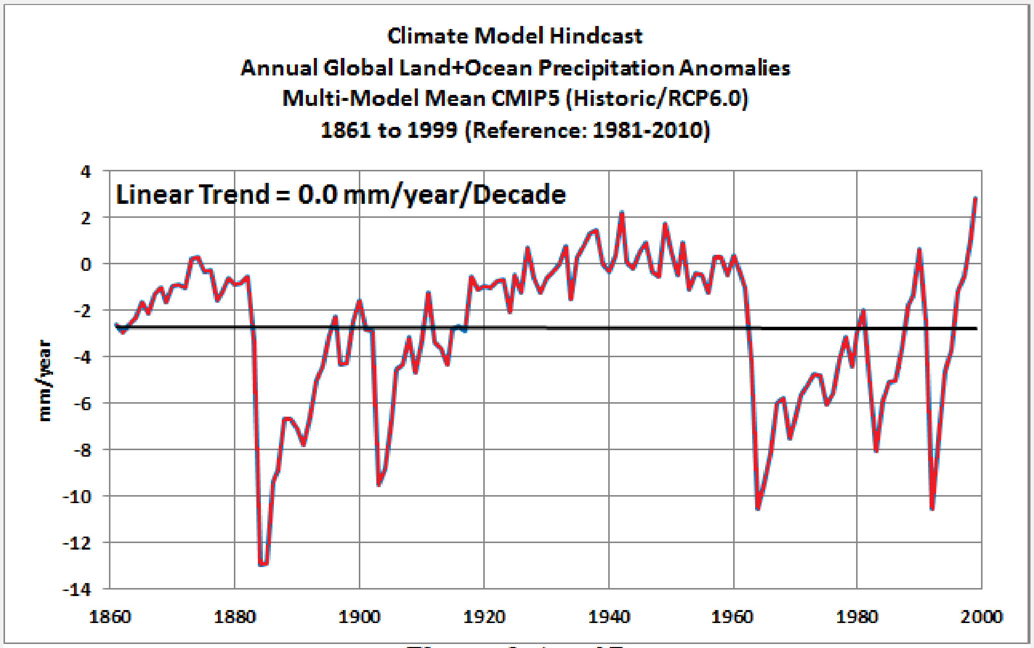


Figure Intro-15

We're constantly told that our current precipitation rates have increased due to human-induced global warming. Yet, as illustrated in Figure Intro-15, based on the linear trend, the average of the climate model simulations of global precipitation (the consensus, the groupthink) show no increase in precipitation from their start year in 1861 to 1999. There are major variations that occur in response to large volcanic eruptions, according to the climate models, but the models show no long-term increase in global precipitation in 140 years.

How then can the alarmist members of the climate-science community tell us that precipitation has increased due to global warming when their models don't show it?

We'll return to Dr. Lindzen's explanation for the answer: It's "…*the fervid imagination of climate activists."*

CLIMATE MODELERS KNEW THE ANSWERS THEY WERE LOOKING FOR AND STILL GOT THE ANSWERS WRONG

Climate models are used to estimate what climate might be like in the future if man-made greenhouse gas emissions continue to rise. And they also are used to simulate past climate here on Earth in an effort to determine how much of the global warming we've already experienced was caused by anthropogenic greenhouse gases. That is, climate models are used to attribute global warming to mankind. But are climate models up to the challenge or have their capabilities been exaggerated? I've already presented numerous examples of very basic climate model failings. Climate models can't properly simulate surface temperatures, sea ice or precipitation. In other words, while climate models have been touted as climate scientists' gifts to mankind, those models, sadly, have little value. Now consider something very important: the modelers already knew the answers (they had data that showed how and when and where surface temperatures had increased, and how and when and where precipitation and sea ice extent had changed) and their climate models still got the answers horribly wrong.

GIVING FALSE HOPE

Not a day goes by without some reporter or blogger writing a news story about a weather event in which the author links a storm or a heat wave…or, quite remarkably, a cold spell…to man-made global warming and human-induced climate change. Before school children can read and write, they are indoctrinated in the evils of fossil fuels. Now, whenever those children hear news of a tornado, a thunderstorm, a drought, a flood, a wildfire, and so on, they believe man-made carbon dioxide caused it. CO_2 is now firmly implanted in their impressionable minds as an omnipotent evil elixir. Windmills, solar arrays and hybrid cars are seen by our children as saviors from those mean and nasty little carbon dioxides.

Of course, we're giving false hope to young people. Littering our landscapes and raising our utility costs with wind farms and solar cells may reduce the emissions of greenhouse gases per unit of electricity (versus fossil-fuel-fired power stations), but those alternative methods of producing electricity are not going to stop tornadoes, or tropical cyclones (hurricanes), or wildfires, or droughts, or floods. Those weather-related phenomena existed long before man set foot on Earth, and they will be with us in the future. Windmills and solar farms are not going to stop them. Even if we could perform the impossible, suck CO_2 from the air and return greenhouse gas levels to pre-industrial levels, life on Earth would not magically become hazard free. Life-threatening weather would still be with us. And there is nothing in the instrument records, as you shall see, to indicate that weather was better…or worse…when CO_2 levels were much lower. Weather is always changing, it's chaotic, and because climate is the average of weather over a multidecadal time period, climate is always changing; climate is simply chaotic weather averaged over periods of 20 to 30 years.

SEA LEVELS, ON THE OTHER HAND, PRESENT AN ENTIRELY DIFFERENT PROBLEM

Again, even if we could turn back CO_2 levels to preindustrial values, sea levels would continue to rise. Sea levels have been rising since the end of the last ice age, and they will continue to do so until Earth cools once again and we head toward another ice age. That is, the only way to stop sea levels from rising is to start accumulating water on land in the form of ice.

Further, the rate at which global sea levels might possibly change in the future, in response to the hypothetical effects of man-made greenhouse gases, is still the subject of wide ranges of uncertainty and open debate…and the subject of even more alarmism from activists and the media, if that's possible.

Let's assume for a moment that climate models properly simulate the possible rises in future sea level, from now through the year 2100. I know it's a big assumption, but we're assuming that for discussion purposes. My Figure Intro-16 is Figure SPM.9 from the 2013 Summary for Policymakers of the IPCC's 5th Assessment Report. The red and blue curves show the central estimates of future sea level rise based on the worst-case (red) and best-case (blue) scenarios, with the lighter red and blue shading showing the full "likely ranges" based on the differences between the models. From current times, the central estimate of the best-case scenario has sea levels rising about 0.45 meters (about 1.5 feet) by 2100, and for the worst-case scenario, the central estimate has sea levels rising near 0.75 meters (about 2.5 feet) by the end of the 21st Century. Or considering the ranges of the best- and worst-case scenarios, the expected sea level rises range somewhere between 0.25 meters (about 0.8 feet) to almost 1.0 meter (more than 3 feet). That's quite a large range, with the worst case scenarios showing the rise in sea levels accelerating. Now, bear in mind, that the best- and worst-case scenarios are basically prognostications of future emissions, which may or may not come true. In other words, there are tremendous uncertainties about future emissions of greenhouse gases above and beyond the very wide ranges of the computer simulations shown in the illustrations.

Figure SPM.9 from the IPCC's AR5 Summary for Policymakers

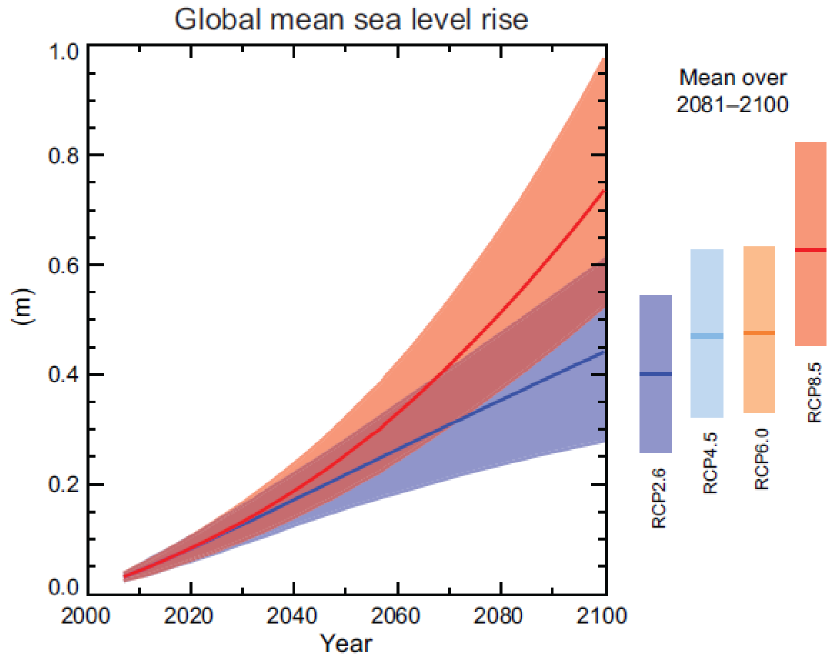


Figure SPM.9 | Projections of global mean sea level rise over the 21st century relative to 1986–2005 from the combination of the CMIP5 ensemble with process-based models, for RCP2.6 and RCP8.5. The assessed *likely* range is shown as a shaded band. The assessed *likely* ranges for the mean over the period 2081–2100 for all RCP scenarios are given as coloured vertical bars, with the corresponding median value given as a horizontal line. For further technical details see the Technical Summary Supplementary Material {Table 13.5, Figures 13.10 and 13.11; Figures TS.21 and TS.22}

Figure Intro-16

(See the note at the end of the Introduction for the citation required by the IPCC for the use of their image.)

Returning to the topic of sea levels accelerating: let's consider a 5-year-old study of sea level data from the United States and around the globe: The title of Houston & Dean's (2010) study Sea-Level Acceleration Based on U.S. Tide Gauges and Extensions of Previous Global-Gauge Analyses would lead you to believe they found sea levels accelerating. But their conclusions indicate the opposite (My boldface.):

> *Our analyses do not indicate acceleration in sea level in U.S. tide gauge records during the 20th century. Instead, for each time period we consider, the records show small decelerations that are consistent with a number of earlier studies of worldwide-gauge records. The decelerations that we obtain are opposite in sign and one to two orders of magnitude less than the +0.07 to +0.28 mm/y² accelerations that are required to reach sea levels predicted for 2100 by Vermeer and Rahmsdorf (2009), Jevrejeva, Moore, and Grinsted (2010), and Grinsted, Moore, and Jevrejeva (2010). Bindoff et al. (2007) note an increase in worldwide temperature from 1906 to 2005 of 0.74°C.* ***It is essential that investigations continue to address why this worldwide-temperature increase has not***

> ***produced acceleration of global sea level over the past 100 years, and indeed why global sea level has possibly decelerated for at least the last 80 years.***

This increases the uncertainty surrounding future sea levels.

Only one thing is certain: the oceans and seas will continue to assault Earth's land masses. No one says sea levels will stop rising if we stop emitting greenhouse gases.

We are not going to stop the oceans from invading our shorelines by adding solar arrays and windmills to power grids or by driving hybrid cars. We can only adapt to rising sea levels…and we have been doing exactly that since the end of the last ice age.

We can no longer travel by land between Asia and North America via the Bering Land "Bridge". Similarly, we can no longer migrate on land between Tasmania, New Guinea and Australia, which were all interconnected landmasses not too many millennia ago. We can no longer hunt and gather in Doggerland, which was the former landmass that once connected Britain to mainland Europe during and after the last ice age. Doggerland disappeared only 6000 to 6500 years ago, swallowed by the rising North Sea. All around the globe, since the last glacial maximum, we've lost valuable low-lying lands and their resources to rising sea levels, and, sadly, we'll continue to lose more of them in the future. That's an unfortunate and unavoidable fact of life on this planet.

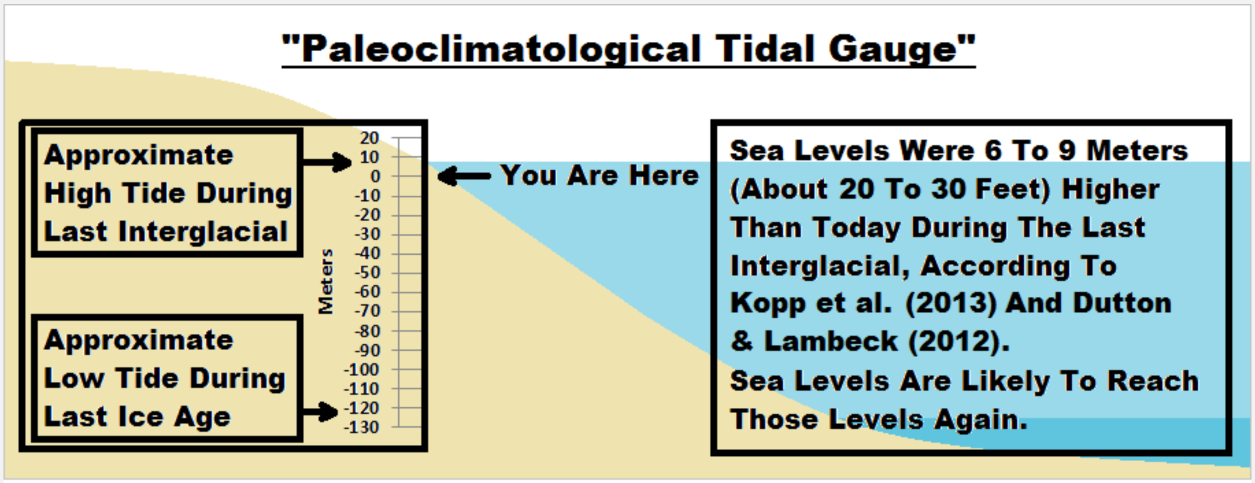


Figure Intro-17

Maybe it's easier to fathom if we look at the rise and fall in sea levels in paleoclimatological timeframes. We won't have to think in those terms often in this book, because most of the discussions are about the past 3 to 4 decades. But for a moment, let's think in tens of thousands and hundreds of thousands of years. Then the 100 to 125 meter (330 to 410 foot) variations in sea levels could simply be thought of as a form of ice age-dependent "tides", washing ashore when the Earth warms between ice ages and retreating when the earth cools toward the glacial maximums. See Figure Intro-17.

Out of need and without the slightest thought of future “tides”, our ancestors built villages, towns and cities along those retreating shorelines. And we continue to build homes there…you simply have to drive the shoreline residential streets along the east coast of the U.S. to see all of the recently built McMansions. Now, with a new-found awareness of those future advances in the “tides”, we are adapting, and future generations will continue to adapt, because our villages, towns and cities lie within the “glacial-interglacial tidal range”. Trying to hold back the “tides” of naturally rising sea levels by limiting greenhouse gas emissions is a fool’s errand. Yet we hear alarmists proclaiming that people won’t react to climate change until their homes are below the rising oceans. One way or the other it’s going to happen sooner or later—2000 years from now or 5000 years from now.

Regardless of whether it’s done proactively or reactively, mankind will continue to adapt gradually, slowly, to the inland march of the seas. There’s no way to avoid it.

Note: For references on the height of sea levels during the last interglacial see:

- Kopp et al. (2013) Probabilistic assessment of sea level variations during the last interglacial stage, and
- Dutton & Lambeck (2012) Ice volume and sea level during the last interglacial.

[End note.]

The ridiculous suggestions by politicians and alarmists that we can control rising sea levels by reducing greenhouse gas emissions is one of the primary reasons for the title of this book: *On Global Warming and the Illusion of Control*.

YOU’D BE WRONG IF YOU THOUGHT THE IPCC WAS A SCIENTIFIC BODY

The Intergovernmental Panel on Climate Change (IPCC) is a political entity, not a scientific one. The IPCC begins the opening paragraphs of its History webpage (my boldface):

> *The Intergovernmental Panel on Climate Change was created in 1988. It was set up by the World Meteorological Organization (WMO) and the United Nations Environment Program (UNEP) to prepare, based on available scientific information, assessments on all aspects of climate change and its impacts, with a view of formulating realistic response strategies.* ***The initial task for the IPCC as outlined in UN General Assembly Resolution 43/53 of 6 December 1988 was to prepare a comprehensive review and recommendations with respect to the state of knowledge of the science of climate change; the social and***

> ***economic impact of climate change, and possible response strategies and elements for inclusion in a possible future international convention on climate.***

Thus, the IPCC was founded to write reports. Granted, they are very detailed reports, so burdensome that few persons read them in their entirety. Of the few people who read them, most only read the Summaries for Policymakers. But are you aware that the language of the IPCC Summary for Policymakers is agreed to by politicians during week-long meetings? A draft is written by the scientists for the politicians, but the politicians debate how each sentence is phrased and whether it is to be included in the summary. And those week-long political debates about the Summary for Policymakers are closed to the public.

Also from that quote above, we can see that the content of IPCC's reports was intended to support an international climate-change treaty. That 1992 treaty is known as the United Nations Framework Convention on Climate Change (UNFCCC). A copy of the UNFCCC is available here. Under the heading of *Article 2 - Objective*, the UNFCCC identifies its goal as limiting the emissions of greenhouse gases (my boldface):

> *The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention,* ***stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system****.*

Because the objective of the UNFCCC treaty is to limit the emissions of man-made greenhouse gases, and because the goal of the IPCC is to prepare reports that supported the treaty, it safe to say the IPCC's sole role is simply to write scientific reports that support the assumed need to limit greenhouse gas emissions. Hmmm. Do you think that focus might limit scientific investigation and understandings?

Later in the opening paragraph of the IPCC's History webpage, they state (my boldface and caps):

> *Today the IPCC's role is as defined in Principles Governing IPCC Work, "...to assess on a comprehensive, objective, open and transparent basis the scientific, technical and socio-economic information relevant to* ***understanding the scientific basis of risk of HUMAN-INDUCED climate change****, its potential impacts and options for adaptation and mitigation.*

The fact that the IPCC has focused all of their efforts on "understanding the scientific basis of risk of **human-induced** climate change" is very important. The IPCC has never realistically tried to determine if natural factors could have caused most of the warming the Earth has experienced over the past century. For decades, they've worn blinders that blocked their views of everything other than the hypothetical impacts of carbon dioxide. The role of the IPCC has always been to prepare reports that support the reduction of greenhouse gas emissions caused by the burning of fossil fuels. As a result, that's where all of the research money goes. The decision to only study human-induced global warming is a political choice, not a scientific one. And it's a horrible choice.

As a result of that political choice, there is little scientific research that attempts to realistically determine how much of the warming we've experienced is attributable to natural factors. We know this is fact because the current generation of climate models—the most complex climate models to date—still cannot simulate naturally occurring ocean-atmosphere processes that can cause Earth's surfaces (and the oceans to depth) to warm for multidecadal periods or stop that warming. Skeptics have confirmed those failings a number of times in blog posts. I even wrote a book about those failings, appropriately titled *Climate Models Fail*.

There is even less scientific research into the benefits of increased levels of atmospheric carbon dioxide, and there are many benefits. Have you ever seen those benefits discussed by the mainstream media?

As you'll discover in this book, the climate models used by the IPCC were never intended to replicate Earth's climate as it exists, because they do not include critical naturally occurring processes. One of the lead authors of numerous IPCC reports—who continues to be an outspoken member of the climate science community—was very open about this after the publication of the IPCC's 4th Assessment Report back in 2007. But what he failed to mention was, because climate models were never intended to simulate Earth's climate as it exists, those models cannot be verified, or even more importantly, they cannot be falsified. That's a fundamental aspect of climate science that few people understand. Climate science as directed by the IPCC is a climate-model-based endeavor, but the models cannot be falsified because they were never intended to simulate Earth's climate as it exists.

Now let's put the naturally occurring long-term (about 3-decades) variations in global temperatures in another perspective. Because climate models were not intended to simulate those variations in climate, a recent study (one with lots of media attention) acknowledged that climate models were not "in-phase" with the real world, and that climate models were not intended to be "in-phase" with the real world. See the abstract of Risby et al. (2014) Well-estimated global surface warming in climate projections selected for ENSO phase, where they state:

> *Some studies and the IPCC Fifth Assessment Report suggest that the recent 15-year period (1998–2012) provides evidence that models are overestimating current temperature evolution* ***. Such comparisons are not evidence against model trends because they represent only one realization where the decadal natural variability component of the model climate is generally not in phase with observations.***

Risby et al. (2014) is a Monday-morning-quarterbacking type of paper that tries to explain away the recent differences between modeled and observed global warming by cherry-picking climate models, which I discussed in the post here.

Imagine if your stock broker revealed their models were not in-phase with the real stock market. What would you do? You'd fire that stock broker on the spot. Unfortunately, we can't do that with the IPCC's climate "brokers".

THE EVOLUTION OF THE CATASTROPHIC ANTHROPOGENIC GLOBAL WARMING MOVEMENT

Unlike some persons, I believe in framing the evolution of the catastrophic anthropogenic global-warming movement as a logical progression…not as a conspiracy.

While there were early scientific studies that pointed to possible increases in surface temperatures associated with the emissions of man-made greenhouse gases, let's begin this discussion with the formation of the report-writing wing of the United Nations called the Intergovernmental Panel on Climate Change (IPCC). As discussed above, the primary task of the IPCC was to create reports that supported the politicians' agendas. Limiting global warming was likely one of those focuses, but most assuredly there were many others.

The politicians found scientists to write those reports—so began the mutually beneficial relationship between climate scientists and politicians. The politicians wanted scientific support for their agendas and the scientists were more than willing to oblige because the politicians held the purse strings for climate research.

The first IPCC report in 1991 was inconclusive, inasmuch as the scientists could not differentiate between man-made and natural warming. In spite of those uncertain findings, a year later the politicians prepared a treaty called the United Nations Framework Convention on Climate Change with the intent of limiting global temperatures to 2 deg C above pre-industrial values—a limit that was first proposed in the mid-1970s by an economist, not a climate scientist.

In the article Two degrees: The history of climate change's 'speed limit' at TheCarbonBrief, authors Mat Hope & Rosamund Pearce write*:*

> *Perhaps surprisingly, the idea that temperature could be used to guide society's response to climate change was first proposed by an economist.*
>
> *In the 1970s, Yale professor William Nordhaus alluded to the danger of passing a threshold of two degrees in a pair of now famous papers, suggesting that warming of more than two degrees would push the climate beyond the limits humans were familiar with:*
>
>> *"According to most sources the range of variation between distinct climatic regimes is on the order of ±5°C, and at present time the global climate is at the high end of this range. If there were global temperatures more than 2° of [sic] 3° above the current average temperature, this would take the climate outside of the range of observations which have been made over the last several hundred thousand years."*

Note: you may be surprised to discover that the 1975 paper by economist Norhaus Can We Control Carbon Dioxide? included a not-too-alarming climate sensitivity to a doubling of CO_2 levels. Nordhaus wrote in his *Introduction*:

> *Because of the selective filtering of radiation, the increased carbon dioxide is thought to lead to an increase in the surface temperature of the planet. Recent extimates [sic] range from 0.6 deg C. to 2.4 deg C. for the mean temperature increase due to a doubling of the atmospheric concentration. (See Sellers (1974), Table 2 for a recent tabulation.)*

Norhaus's referenced paper is Sellers (1974) A Reassessment of the Effects of CO_2 Variations on a Simple Global Climatic Model.

We'll discuss climate sensitivity later in this book.

[End note.]

In the early 1990s, the politicians continued to fling funds at scientists with hope the next report would provide support for their agendas. Much to the politicians' astonishment, the scientists' initial draft of the 1995 Summary for Policymakers for the 2nd Assessment Report from the IPCC was still inconclusive.

Imagine that. In 1992, the United Nations had convinced many countries around the globe to enter into a treaty to limit emissions of greenhouse gases, when a year before the IPCC could not find mankind's fingerprint on global warming. Then, by 1995, the politicians' scientific report-writing body, the IPCC, still could not differentiate between man-made and natural warming, and the climate scientists had stated that fact in the draft of the second IPCC assessment report. The politicians were between the rock and the hard place. They'd had a treaty in place for 3 years but their report-writing scientists could not find evidence to support it.

So, after most of the scientists had left the meeting, the politicians and a lone scientist changed the language of the second IPCC assessment report in a very subtle but meaningful way. *Voila!* The politicians and one scientist initiated what is now called the consensus. (See the 3-part, very detailed analysis by Bernie Lewin about the 1995 IPCC conference in Madrid. Part one is here.)

Now consider that modes of natural variability that can have long-term effects on weather patterns and can enhance and suppress global warming were identified after the creation of the consensus in 1995. To this day, climate models still do not consider those modes of natural variability, and modelers are not even close to being able to simulate them…thus, all of the excuses—dozens of excuses—for the slowdown in global warming.

Mainstream media have been more than willing to add their attention-grabbing sound bites to global-warming news, in an effort to increase viewer/reader numbers and pump up advertising revenues.

Like the relationship between climate scientist and politician/climate-science funder, there is a mutually beneficial bond between climate scientists and mainstream media. Predictions of gloom and doom from climate scientists help sell newspapers and help keep viewers tuned in to their networks and websites, which help maintain or increase advertising revenues for the news outlets. The media, in return, have afforded many climate scientists more than their 15 minutes of fame, making some of them household names. And keeping the assumed threats of global warming in the public eye allows the politicians to throw more money at climate scientists.

Many fields of science found a new source of funding in global warming and climate change. Climate might have held little interest in the past for many research disciplines, but that changed when scientists discovered the deep well of research funds available for climate-related research. To assure that moneys were supplied from government coffers, needy scientists, with nowhere else to turn for their off-topic research, had only to include the terms global warming or climate change in their applications for research grants. Regardless of what field those scientists were studying, moneys flowed.

The overselling of calamities in environmental sciences has reached unseemly proportions…so much so for one field that in 2014 a team of marine researchers exposed the problems in a journal article. The paper is Duarte et al. (2014) Reconsidering Ocean Calamities. The abstract reads (my boldface):

> *The proliferation of a number of pressures affecting the ocean is leading to a growing concern that the state of the ocean is compromised, which is driving society into pessimism. Ocean calamities are disruptive changes to ocean ecosystems that have profound impacts and that are widespread or global in scope. However,* ***scrutiny of ocean calamities to ensure that they can be confidently attributed to human drivers, operate at widespread or global scales, and cause severe disruptions of marine social-ecosystems shows that some of the problems fail to meet these requirements or that the evidence is equivocal. A number of biases internal and external to the scientific community contribute to perpetuating the perception of ocean calamities in the absence of robust evidence.*** *An organized auditing of ocean calamities may deliver a more precise diagnosis of the status of the oceans, which may help to identify the most pressing problems that need be addressed to conserve a healthy ocean.*

Also see the *Nature* editorial Ocean 'calamities' oversold, say researchers. Those problems run rampant in climate science.

The politicians plowed ahead with their objectives, and another international agreement was signed in 1995, which set goals to reduce the emissions of man-made greenhouse gases. That agreement is known as the Kyoto Protocol. But key countries, like the United States, never ratified the treaty and were not bound by it.

Something unseen was going on at the same time. A remarkable series of naturally occurring weather events, starting in 1995, allowed the sun to heat part of the Pacific Ocean and supply the warm water that served as fuel for a monstrous El Niño a few years later. That super El Niño besieged the eastern tropical Pacific (which stretches more than ¼ of the way around the globe) and caused the sea surfaces there to temporarily warm (naturally) in places as much a 5 deg C (9 deg F). That El Niño began in 1997 and ended in 1998. The consequences of that strong El Niño could be seen in weather almost everywhere on Earth. Meteorologists had known for decades that strong El Niños can have drastic impacts on weather around the globe, and the 1997/98 El Niño provided examples at biblical scales. Every drop of rain, flake of snow—or their absences—every flood or drought, every heat wave or cold spell was blamed on that El Niño…and in many cases it was correct to place the blame on the El Niño. El Niño became the excuse for anything and everything. Late for work? Blame it on El Niño. There were cartoons, even a *Saturday Night Live* comedy sketch. The trailing 3-year-long La Niña skewed weather around the globe again, with many of the effects being the opposite of those during the preceding El Niño. The jokes continued.

That untimely change of public interest must have horrified politicians. Mother Nature, in her magnificent forms of El Niño and La Niña, had stolen the limelight from man-made global warming and may have slowed the continued implementation of the additional political agendas.

The IPCC's 3rd Assessment Report in 2001 helped politicians refocus the public's attention back on the contrived evils of man-made greenhouse gases. Slowly but surely the likeminded media worked to transfer the blame for weather from nature to man-made greenhouse gases, with the help of outspoken climate scientists, regardless of whether models and data supported the claims. (We'll address some of those claims right off the get go in General Discussion A.)

The 2007 4th Assessment Report from the IPCC was helped by Al Gore's movie *An Inconvenient Truth*. Also keeping global warming and climate change in the public's eyes were the award of Nobel Peace Prizes to Gore (a politician) and the IPCC (a political report-writing body)…and the award of an Oscar to Gore for *An Inconvenient Truth*.

All along, politicians were working on language for a new treaty to replace the Kyoto Protocol, which expired in 2012. Meetings have been held annually in efforts to hammer out language that is acceptable to all nations, with no success. Hampering those efforts are the normal needs and wants of developed versus developing nations. Further hurting any new treaty has been the limited successes of the Kyoto Protocol. Nations that made concerted efforts to reduce emissions have damaged their economies, wounding the finances of all but a relatively few residents…some of whom like vampires have drained funds from government coffers. Unemployment soared. The number of pensioners freezing to death in their homes increased, because more seniors couldn't afford to heat them. Alternate energy sources like wind and solar have only been viable because of government subsidies, and many nations have come to realize they're throwing good money after bad by keeping the wind and solar industries alive. Globally, greenhouse gas emissions continue to soar, because China and India are ramping up their coal-fired power plants, trying to provide basic electric service and other amenities to their people.

Imagine something for a moment: about one-third of the population of India lives without electric service in their homes. That's 400 million souls in Indian alone without a service we take for granted.

Oddly, one of the nations that was most successful at limiting the growth of greenhouse gas emissions has been the United States, which wasn't bound by that Kyoto agreement. That success, however, was due primarily to a shift from coal to natural gas…a shift that was sought by and achieved by power companies.

Bottom line: When the promotion of global warming and climate change is viewed as a mutually beneficial relationship between politicians, climate scientists and the mainstream media, there is no need to frame it as a conspiracy.

SAME-OLD, SAME OLD

Consider this: There really hasn't really been anything new from the IPCC since its first assessment report. Each of the subsequent IPCC assessment reports—and there have been a total of 5 so far—has fundamentally presented the same things. They are, if man continues to emit greenhouse gases at increasing rates:

- global surfaces will warm;
- the oceans will warm to depth, but at extremely low rates;
- sea ice, ice sheets and glaciers will melt;
- droughts and floods will occur, though they can't tell us where and when; and
- sea levels will rise.

The estimated rates of future global surface warming and their wide simulated ranges are basically the same in the 5th assessment report as they were in the 1st, leading many persons to wonder why we continue to pump tens of billions of dollars annually into climate research when we keep getting the same-old answers.

Can the climate science community tell us where and during which decades those droughts or floods will occur? No. The groupthink-supporting scientists can only tell us life will be worse in the future—without any data-based evidence to support the claims of increasing catastrophes. (See General Discussion A.)

THE ECONOMICS OF BREAKING THE 2 DEG C THRESHOLD OF DOOM

The 2 deg C target may have been initiated by an economist in the mid-1970s. Forty years later, another economist argues that the economic impacts of climate change will be small. Those are the findings of Dr. Richard T. S. Tol, Professor of Economics at the University of Sussex. See Dr. Tol's article What is the global economic impact of climate change? at WorldEconomicForum.org. Dr. Tol writes:

> *A global warming of 2.5ºC would make the average person feel as if she had lost 1.3% of her income, 1.3% being the average of the 11 estimates at 2.5ºC. These estimates were derived using a range of well established and accepted methods, the complaints of Pindyck (2013) notwithstanding.*

Regarding climate change and the poor, Dr. Tol continues:

> *There are two ways to mitigate the excessive impact of climate change on the poor: reduce climate change, and reduce poverty. A fifth of official development*

> *aid is now diverted to climate policy (Tol 2014). Access to energy is a key part of development. Coal is the cheapest way to make electricity, but emits most carbon dioxide. Overly ambitious climate policy may make the impacts of climate change worse rather than better.*

And the conclusion of Dr. Tol's article reads:

> *In sum, breaking the 2ºC target is not a disaster. The most serious impacts are symptoms of poverty rather than climate change. Other impacts are unlikely to have a substantial effect on human welfare.*

DATA

Data are the backbone of the science behind global warming and climate change. That is why introductory discussions of datasets will occupy a future Part 2 of this book. Without data, there would be no evidence of long-term changes in temperature or weather. That is, we as individuals would not likely be able to sense that global surface temperatures have warmed. Daily and seasonal variations in temperature are so great that the slight change in global surface temperature we've experienced since the mid-1970s would go unnoticed. It's only about 0.6 deg C or 1.1 deg F. The only reason we're aware global temperatures have increased is the constant hoopla we hear, read and see in the news. Changes in weather might be noticeable over time. Some years, there's less rain and snow at your home and in other years there's more. Without data, we'd have to rely on memories.

Because surface temperature and other related data do exist, numerous industries have evolved to document, model and research human-induced global warming and climate change. In turn, opportunistic, parasitic organizations materialized and their goals have been to generate fear and to promote corrective products and life-style changes that might (no guarantees) contribute to a reduction in the hypothetical long-term warming. If the global-warming scare were to evaporate in the imaginations of consumers, those self-absorbed industries would wither and die. They would be long, painful and very vocal deaths, because those organizations have invested decades and billions.

But do data support the hypothesis of man-made global warming? The Earth has warmed over the past century, numerous datasets indicate that it has, but do they confirm or contradict the notion that humans caused the warming? If you continue to read this book, you'll find surprising answers to those questions.

Specialized satellites have orbited the Earth since the late 1970s, and aboard them are devices scientists can use to calculate the temperatures at various levels of the atmosphere. One level is the lower troposphere, and it is basically focused on the altitudes of sea level to about 3,000 meters (about 10,000 feet), but extends as high as

12,500 meters (41,000 feet) in the tropics. Figure Intro-18 illustrates the annual global lower troposphere temperatures from 1979 to 2014. The supplier of the data is Remote Sensing Systems (RSS), and it is available in easy-to-use formats from RSS and via a web tool created by Dr. Geert Jan van Oldenborgh of the Royal Netherlands Meteorological Institute (KNMI) called Climate Explorer. KNMI's Climate Explorer is a wonderful tool if you like to investigate climate-related data and climate model outputs.

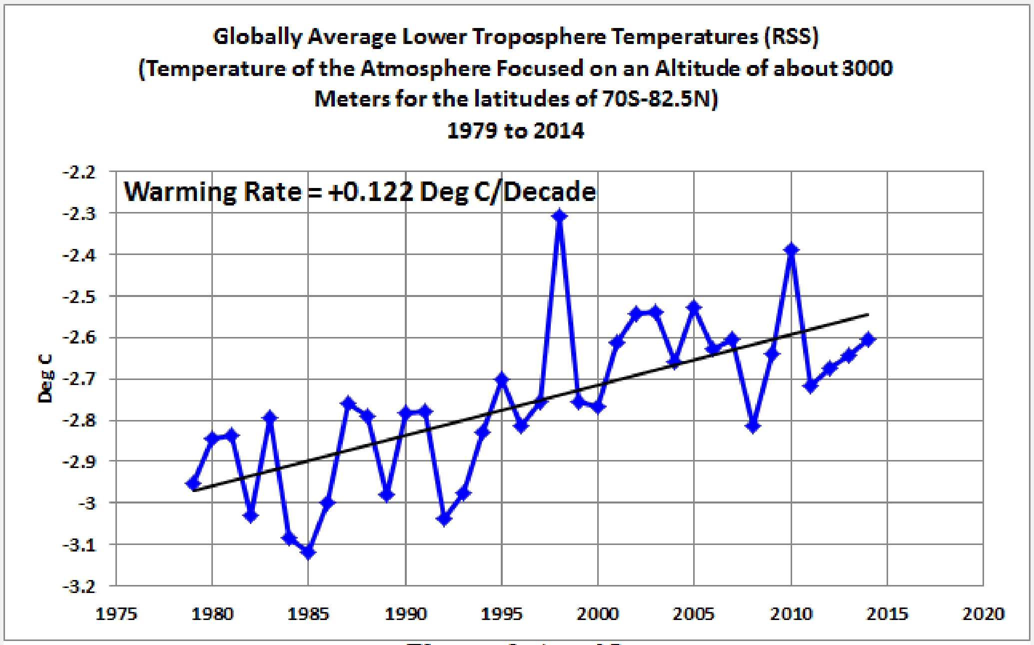


Figure Intro-18

As illustrated, it's chilly up there in the lower troposphere, with the global annual temperature averaging about -2.75 deg C (about 27.0 deg F) for the period of 1979 to 2014. Spreadsheets have a statistical program you can use to determine the linear trend of data, and we can see that the warming rate was about +0.12 deg C/decade (about +0.23 deg F/decade) over the past 35 years. Note how the lower troposphere temperatures in 2014 were nowhere close to being at record-high levels.

We can also see that the warming was anything but smooth. There are large upward spikes caused by El Niño events, and there are downward troughs caused mostly by La Niña events. Some of the dips are also caused by the sunlight-blocking aerosols spewed into the stratosphere by catastrophic, explosive volcanic eruptions—El Chichon in 1982 and Mount Pinatubo in 1991.

Surface temperature data, on the other hand, come from surface air temperature stations (i.e. weather stations) on land (about 30%), and from the measurements of the surface temperatures of the oceans and seas (about 70%). There are three primary suppliers:

- NASA Goddard Institute for Space Studies
- NOAA National Climatic Data Center
- UK Met Office

I've averaged them for Figure Intro-19, below, using the monthly data for the period of January 1945 to December 2014. Those three suppliers present their data as anomalies (deviations from the averages for a given period).

DO NATURALLY OCCURRING, SUNLIGHT-FUELED PROCESSES CONTRIBUTE TO GLOBAL WARMING?

According to the IPCC, only man-made greenhouse gases can explain the global warming in recent decades. What the IPCC fails to mention: the climate models they use for attribution studies cannot simulate the naturally occurring, sunlight-fueled ocean-atmosphere processes that can and do contribute to global warming.

I've highlighted four periods in Figure Intro-19. Those periods are similar to those in a graph prepared by Dr. Kevin Trenberth, of the National Center for Atmospheric Research, for a May 2013 Royal Meteorological Society (RMS) article titled Has Global Warming Stalled? Dr. Trenberth was a lead author of the Intergovernmental Panel on Climate Change's 3rd and 4th Assessment Reports. He has been an outspoken advocate of the hypothesis of human-induced global warming for decades.

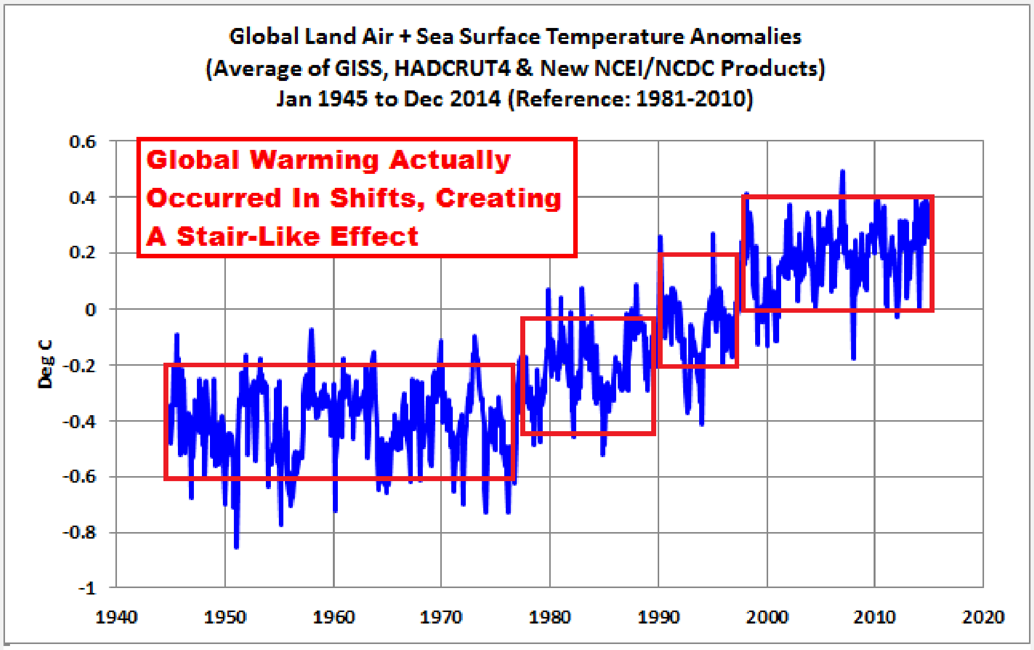


Figure Intro-19

In his article for the Royal Meteorological Society, Dr. Trenberth was trying to downplay the significance of the recent slowdown in the warming of global surfaces—a.k.a. the hiatus or pause. Global surface temperatures, of course, are the primary metric used in discussions of human-induced global warming. He noted that decade-long periods of no warming were commonplace and that global surface temperatures actually warmed in “big jumps” with decade-long hiatus periods between the jumps. Curiously, skeptics have been discussing these step-like increases in global surface temperatures and the reasons for them for more than 6 years. Dr. Trenberth failed to present the causes of those “big jumps” in that article. So, in the blog post Open Letter to the Royal Meteorological Society Regarding Dr. Trenberth’s Article “Has Global Warming Stalled?”, I was more than happy to inform and remind the Royal Meteorological Society that:

- the “big jumps” were caused by strong El Niño events,
- El Niño events occur naturally and
- El Niño events are fueled by sunlight-created warm water, as Dr. Trenberth had stated in an earlier paper.

In later interviews, Dr. Trenberth admitted that El Niño events were the cause of the jumps in global surface temperatures…and he has also noted in two scientific papers that El Niño events are fueled by sunlight. (See the post The 2014/15 El Niño – Part 9 – Kevin Trenberth is Looking Forward to Another “Big Jump”.)

In 2014, another El Niño was brewing in the tropical Pacific Ocean, and climate-based-policy promoters were chomping at the bit because it might have brought a perceived end to the slowdown in global warming. Further to his past discussions, Dr. Trenberth suggested another upward shift in global surface temperature might be in store as a result of the El Niño. Were you aware than El Niño events caused long-term global warming? I’ve been documenting and discussing this for 6 years, and now, finally, one prominent member of the climate science community has acknowledged that El Niño events contribute to global warming…and, as noted earlier, he also notes that El Niño events are fueled by sunlight, not man-made greenhouse gases. An introduction to those processes will be discussed and illustrated later in the book.

A weak El Niño formed last year, nothing capable of causing an upward shift, but the El Niño has strengthened in 2015, and Dr. Trenberth is back on his soapbox proclaiming another upward shift might occur, while neglecting to inform the reporters that El Niños are fueled by the sun. Or maybe Dr. Trenberth does inform the reporters of that basic reality and the reporters choose to ignore it.

THEY SAY THAT SUNLIGHT CAN’T BE THE CAUSE OF GLOBAL WARMING

Speaking of sunlight, it is often said that variations in our sun’s output could not be the cause of the warming since the 1970s. The reason: the output of the sun has actually declined slightly in that time and, thus, the amount of solar radiation reaching the top of Earth's atmosphere has also decreased slightly.

But it's the amount of sunlight reaching the Earth's surface that's important, not how much has reached the top of the atmosphere. The primary things that can cause variations in the amount of sunlight reaching Earth's surface are clouds and both natural and man-made aerosols.

So how much sunlight has reached the Earth's surface in recent decades?

Unfortunately, there are only a few long-term measurements of the amount of sunlight reaching land surfaces and basically no long-term data for sunlight reaching and penetrating into the oceans. Climate scientists must rely on specialized climate models that use data as inputs…like satellite measurements of cloud amount, the optical thickness of aerosols from volcanos and, of course, the sunlight at the top of the atmosphere. A specialized model like that is called a reanalysis. The metric for sunlight at the surface is known as downward shortwave radiation at the surface, or surface DSR. It may come as a surprise to you that at least one reanalysis shows the amount of sunlight reaching Earth's surface has increased drastically since 1979. See Figure Intro-20.

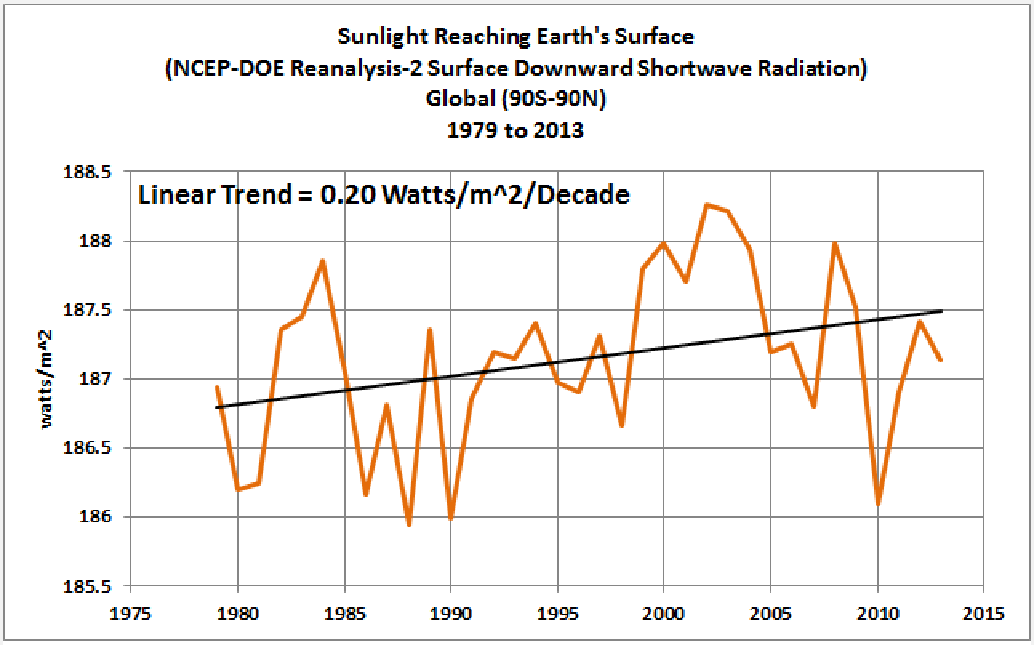


Figure Intro-20

That reanalysis is the NCEP-DOE Reanalysis-2, and it is a product of the NOAA National Centers for Environmental Predictions (NCEP) and the U.S. Department of Energy (DOE) . It is supported by the 2002 paper NCEP-DOE AMIP-II Reanalysis (R-2) by Kanamitsu et al., which has been cited by several hundred other scientific papers.

Yet it is very rare when there is even the slightest whisper of the possibility that sunlight reaching Earth's could have been the primary cause of the global warming we've seen since the late 1970s.

NOTE: Sadly, Figure Intro-20 is one of the few graphs in this book that you would not be able to easily verify with online source materials. In 2014, NOAA began renovating their National Model Archive and Distribution System (NOMADS). As part of those changes, NOAA (temporarily?) removed the NCEP-DOE reanalysis from NOMADS. Many of the metrics supplied by NOAA from the NCEP-DOE reanalysis had been (past tense) also available through the KNMI Climate Explorer, but KNMI also removed that NCEP-DOE reanalysis from their website. The outputs of that reanalysis are no longer available anywhere to the public, as far as I know, in an easy-to-use format.

I had presented that graph, or similar ones, in a number of blog posts in recent years when the output of the NCEP-DOE reanalysis was available, and readers are always double-checking my graphs with controversial or interesting results…as do I. If I had erred with the graph in Figure Intro-20, we would have known about it. [End note.]

IT IS DIFFICULT IF NOT IMPOSSIBLE TO LOOK AT A TIME-SERIES GRAPH OF GLOBAL TEMPERATURES AND DETERMINE WHAT CAUSED THE WARMING

There are numerous temperature-related datasets and all of them—from land surface air temperatures…to sea surface temperatures…to the temperatures of the oceans for depths of 2000 meters (about 6550 feet)—point to an Earth that had warmed. We'll discuss those datasets in detail in the upcoming part 2 of this book.

But looking at a time-series graph of global data, can we hope to determine whether natural or man-made factors caused the warming?

Nope.

We can only see that global temperatures have increased. It doesn't tell us where or why they have warmed. As discussed earlier, Dr. Trenberth suggests there are naturally occurring processes that can cause the long-term warming of global surface temperatures, but then in the next breath he talks about the consequences of man-made global warming. So which is responsible for the warming, man-made greenhouse gases or natural factors? Whether he intended to or not, Dr. Trenberth has muddied the waters of CO_2-driven global warming.

THE GLOBAL-WARMING DEBATE IS NOT TAKING PLACE IN SCIENTIFIC JOURNALS

And there are very obvious reasons why the global warming/climate change debate is not taking place in scientific journals. The climate model-founded and politically motivated groupthink about the human impacts of global warming is so firmly fixed in place that it is nearly impossible to publish papers that challenge it. Scientists who question the dogma are likely to lose government funding and/or their jobs. Those who do write papers along those lines run into more roadblocks. Editors of scientific journals shy away from studies that do not agree with the politics-founded groupthink for a number of reasons…one of which happened not long ago when a couple of extremist groupthink scientists threatened to boycott a scientific journal because that journal had published a skeptical paper. That was revealed by the ClimateGate emails. (See Climategate: The Crutape Letters by Mosher and Fuller published in 2010.) Some journal editors have had to look for new jobs after publishing a paper that threatened the global-warming consensus. Even if an editor were to initially accept such a paper for consideration, it is hard to imagine it making it past the watchful eyes of the peer-reviewers who guard the funding interests of the groupthink.

The vast majority of the global-warming debate takes place in blogs as a result. It may come as a surprise to you, but people are most interested in blogs that are skeptical of catastrophic global warming, with WattsUpWithThat the most-viewed website on global warming and climate change. As noted earlier, I am a regular contributor to WattsUpWithThat. I view my role as that of an investigative reporter—one who presents and discusses coupled ocean-air processes, data and climate model outputs.

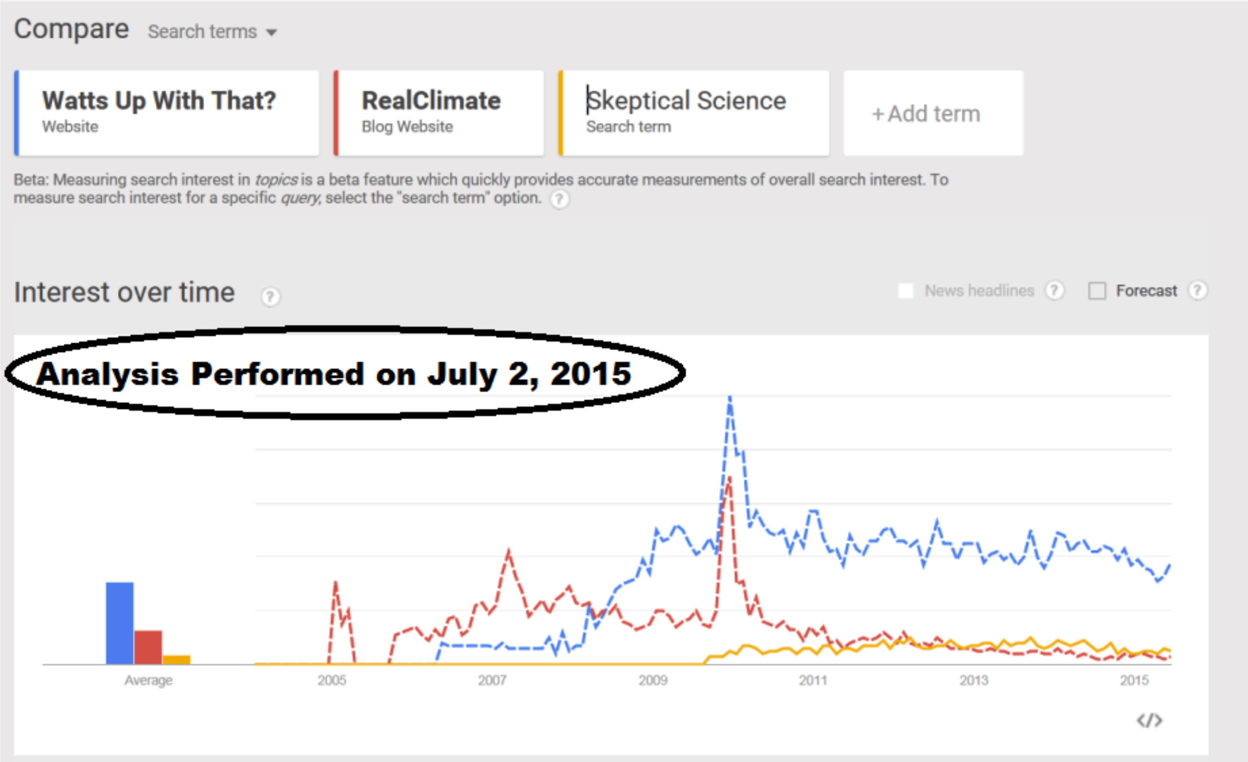


Figure Intro-21

Figure Intro-21 is a screen capture of Google Trends results for the three global-warming blogs that garner the most public interest. They are Watts Up With That? (blue), Real Climate (red) and Skeptical Science (orange). RealClimate is a blog founded in 2004 and it's operated by climate scientists from around the globe. SkepticalScience, on the other hand, is operated primarily by enthusiasts (not scientists) who parrot the dogma of human-induced global warming. Interest in SkepticalScience began in late 2009 when they were founded. WattsUpWithThat, founded in 2008, represents the skeptics.

The horizontal axis (x-axis) in Figure Intro-21 is time measured in months, and the vertical axis (y-axis) is Googled interest from 0 to 100% for those search terms. Of the three websites, WattsUpWithThat established the most Google interest in December 2009. That was when the controversial ClimateGate emails were released. (See Climategate: The Crutape Letters by Mosher and Fuller published in 2010.) The y-axis of the Google Trends graph is then compared to that December 2009 interest level in WattsUpWithThat. ClimateGate also caused a spike in interest at RealClimate, and that makes sense because many on the emails that showed scientists behaving badly were from the climate scientists who founded RealClimate. ClimateGate may have sparked the public's interest in the blog SkepticalScience, though that would be difficult to determine because that website was founded around that time.

One thing is certain: Public interest in the skeptical website WattsUpWithThat dwarfs even the sum of those two competitors.

Looking at the graph above, it's obvious most people seek out alternate viewpoints from weblogs run by climate skeptics. And WattsUpWithThat is the world's most-visited website on global warming and climate change. WattsUpWithThat was voted "Best Science Blog" in the 2008, 2011, 2012 and 2013 in the Annual Weblog Awards. In 2014, WattsUpWithThat took the awards for "Best Group or Community Weblog" and "Weblog of the Year", after the Bloggies eliminated the category for best science blog. WattsUpWithThat is run by meteorologist Anthony Watts, who is ultimately responsible for the quality of the website and its success.

I am very proud to be a regular contributing author at WattsUpWithThat.

PUBLIC INTEREST IN SKEPTICISM DOES NOT SIT WELL WITH THE CO_2 OBSESSED

That public interest in WattsUpWithThat has spawned other blogs, where the authors and visitors whine about the articles at WattsUpWithThat. It's quite remarkable when you think about it: a blog skeptical of many aspects of human-induced global warming has produced other blogs, where the sole intent of the spawned blogs is to attempt to undermine skeptic arguments. Many of the bloggers at those websites were banned from WattsUpWithThat for their troll-like behavior. Because I am a regular contributor at WattsUpWithThat, my blog posts are often attacked at those spawned blogs. If you were to Google my name *Bob Tisdale*, you'd find links to examples. The tactics they employ include misquoting, quoting out of context, deliberate misinterpretation and misrepresentation, outright fabrications, etc. They often claim I have not explained or documented how certain processes work, when, in reality, I've done so in a multitude of articles. Their blog posts are normally nothing more than obvious expressions of their misunderstandings and their blatant attempts to mislead their readers.

One of the most remarkable tactics they use is contradiction, reminiscent of the Monty Python "Argument Clinic" sketch. For example, many times in a blog post I will show the flaws in *Topic A* by presenting *Data B*, *Data C* and *Climate Model Output D*. Then, to counter my blog post, the spawned blog will simply present *Topic A* again, saying *Topic A* is correct because they say so, without addressing my arguments of *Data B* and *Data C* and *Climate Model Output D.* The authors of those posts are simply arguing for argument's sake, and not addressing what I've presented. It's one of the silliest debate tactics imaginable, and they use it all of the time.

Other times, the author at a blog critical of my posts at WattsUpWithThat will admit to not understanding a topic, yet that author will then go on to write a full-length blog post about it. It's quite amazing.

I expect to see the same underhanded debate tactics when they comment about this book. I welcome them, because I find them amusing.

GLOBAL-WARMING FANATICS OR MERCHANTS?

Many of the blog and newspaper articles we see almost daily are written by people who are obsessed with global warming. To many of them, any warming is bad. It doesn't matter whether the warming is natural or anthropogenic. In their minds and hearts, any miniscule increase in annual global surface temperatures brings us closer to gloom and doom.

I suspect those persons have focused on the politician's 2-deg C threshold. And even though paleoclimatological studies have shown that global surface temperatures can be 2-deg C or warmer than today during interglacial periods (periods between ice ages), the global-warming obsessed have taken the 2-deg C limit to heart. Imagine waking every morning with the fixed belief that every minor change in your local weather is something to be feared and is a sign from Mother Nature of even worse things to come. It's impossible to discuss the skeptical viewpoints of global warming with someone so obsessed.

Unfortunately, it's also difficult at best to differentiate those persons from global warming merchants…those who are using global warming and climate change for their political or financial gain or both. Many of the persons you believe are interested in "saving the planet" may, in fact, be only interested in increasing their political power or lining their pockets.

MOST PEOPLE VIEW GLOBAL WARMING AND CLIMATE CHANGE AS LOW PRIORITIES…EVEN WITH THE HYPE

Human-induced global warming/climate change is said to be one of the greatest problems facing mankind and the future of our planet Earth, but polls indicate global warming and climate change are only major concerns for respondents when polls are solely about global warming or climate change. On the other hand, when polls include concerns about other factors that impact people's lives—unemployment, health care, the federal deficit and government spending, the cost of living, rising energy costs, and the like—global warming ranks near the bottom of people's priorities. See the March 12, 2014 Gallup.com article Climate Change Not a Top Worry in U.S. and also see the MyWorld2015.org poll The United Nations Global Survey for a Better World.

Consider something very important when looking at the results of online or telephone polls. They are not accounting for the opinions of people without internet or telephone access…or, likely, people without electric service and televisions. It's hard to imagine those people—some who live in shacks and use dung-fueled fires for heating, light and cooking—would even consider global warming in their day-to-day concerns. Would many of those people have even heard of the hypothesis of human-induced global warming?

Back to the results of those polls: Now consider the tens of billions of dollars that have been pumped into global-warming research and into promoting the hypothesis—much of it used in preparing the assessment reports of the Intergovernmental Panel on Climate Change—and one might conclude the government agencies footing the bill are not getting a good return on their investment.

Most people do not have the time, the inclination, and, in many cases, the ability to investigate the hypothesis of man-made global warming. After a long workday, who wants to analyze temperature or precipitation data and check the climate model simulations of them? Very few people. Most persons get their information about climate change from the news—TV, newspapers, magazines and online—hopefully understanding that most of what they're heard, seen and read from the mainstream media is hype. The news outlets, of course, want to catch your eye and keep you tuned to their broadcasts…and to do that, everything must be exaggerated. Do the talking heads tell us the low-to-mid range of the climate model estimates? No. Do they tell you what lovely weather we had over most of the planet today? Of course not. They only present the worst-case scenarios and attention-grabbing, heart-wrenching disasters…because they want keep viewers glued to their TVs or computer screens, and, by doing so, increase their advertising revenues. Many persons understand the hype and also understand that climate science is motivated by politics and funded by agenda-driven government entities. Sadly, others do not understand those fundamental realities.

GLOBAL WARMING SKEPTICS ARE NOT GLOBAL WARMING DENIERS

Promoters of the hypothesis of human-induced global warming and their alarmist compatriots often refer to skeptics as global warming deniers. It's an odd label for skeptics, because most of the prominent skeptics do not deny that the Earth has warmed or that climate changes. In fact we illustrate those facts in almost every blog post and article we prepare. Most skeptics understand:

- humans changed Earth's environment
- man-made greenhouse gases contribute to the warming of the atmosphere, and
- humans have contributed to climate change in many other ways.

However, most prominent skeptics are:

- NOT convinced that mankind is responsible for most of the global warming we've experienced,
- NOT convinced future global warming will lead to additional climate catastrophes, and
- definitely NOT convinced that the climate science community can attribute to mankind any of the global warming and changes in climate we've experienced…because their models cannot simulate the basic natural processes that can cause global warming or stop it cold.

Those are the skeptical views presented in this book.

HUMAN-INDUCED GLOBAL WARMING DOES EXIST, BUT DATA SHOW ITS IMPACTS HAVE BEEN GROSSLY OVERSTATED

Now, I'm not saying that mankind has not contributed to global warming or changed climate on Earth. We've cut down forests to build homes, and we've turned deserts into farmland. We've covered the Earth's surface with sunlight-absorbing, heat producing blacktop so we can travel conveniently by cars and buses, and so we can transport goods and food from where they're produced to where they're consumed. We've dammed rivers to produce electricity, we've redirected rivers to supply water to cities with insufficient local sources, and we've pumped vast amounts of water from the ground for numerous purposes…from drinking and cooking to bathing and cleaning to irrigation and so on. And we've added greenhouse gases like carbon dioxide and methane to the atmosphere.

I'm also not suggesting that we shouldn't take efforts to make the Earth a better place for future generations. But, as noted earlier, alternative methods of producing electricity are not going to stop dangerous weather events or stop our rising seas. The same holds true for capping emissions of carbon dioxide from power plants and for increasing vehicle mileage standards. Windmills and solar farms and hybrid cars are not going to stop weather events. And as we'll show using data, there is no evidence of increases in the frequencies or destructiveness of those catastrophic events.

The data presented in this book do not disprove the hypothesis of human-induced global warming. They do, however, show that impacts of human-induced global warming have been grossly overstated. For more than six years, I have been presenting ocean-based temperature and heat content data that indicate naturally occurring ocean-atmosphere processes are the primary causes of ocean warming, not man-made greenhouse gases—or as I've noted many times over the years, I've searched the ocean data and I can find no evidence of human-induced global warming. I'll show you that evidence again in this book.

Further, the discussions in this book show the many faults in the hypothesis of man-made global warming and show very clearly, using data from the real world, that climate models are flawed…so flawed they have little use when trying to attribute past global warming to mankind and no value when trying to predict how climate might change in the future. That is, climate models have not yet reached the point where they are fit for their intended purpose. Climate models will only be fit for that purpose when they can simulate the naturally occurring processes that can contribute to and suppress the warming of our Earth.

ACRONYMS

Every industry and field of science has their own set of acronyms, and unless you're familiar with them, they add another hurdle toward understanding that field. Many times, the authors of a climate study of a particular metric in a specific region will create new acronyms for that one-time paper, requiring readers to temporarily learn even more acronyms. With the exception of government departments like NOAA for National Oceanographic and Atmospheric Administration, UKMO for United Kingdom Met Office (originally Meteorological Office), or company names like RSS for Remote Sensing Systems, etc., I have tried to avoid acronyms in this book where possible. I include them parenthetically in the openings of chapters so you can be familiar with them, but for *On Global Warming and the Illusion of Control*, you will not have to learn that SST stands for sea surface temperature, OHC for ocean heat content, TLT for lower troposphere temperature, and the like.

The other exception to the rule: Data suppliers also use acronyms for their datasets. Example: HADISST, which stands for UKMO's *Hadley Centre Sea Ice and Sea Surface Temperature data set*. There is very limited space in the title blocks of the graphs, so I identify the dataset used in the graph by its initials. See the example in Figure Intro-22 that follows.

A FEW MORE SAMPLE ILLUSTRATIONS

Many of the illustrations later in this book are graphs that compare data for a given variable, such as surface temperature, with the outputs of climate model simulations of that variable. In other words, they compare the real world to the virtual worlds of the climate models.

I've been presenting comparison graphs of climate model outputs and data from the real world for a number of years. True-blue believers in human-induced global warming do not appreciate them. One of their repeated complaints is that I try to make the models look bad. But that requires no effort on my part. The climate models used by the IPCC for their most recent report perform terribly all on their own.

We'll discuss this in more detail later in the book, in simpler terms (See Chapter 2.11 – Different Ways to Present Climate Model Outputs in Time-Series Graphs: The Pros, the Cons and the Smoke and Mirrors.) But as an introduction: In many presentations, the climate model outputs in this book are represented by the average of all of the outputs of the dozens of individual climate model runs. That average is known as the model mean. And the models presented are the ones stored in the archive called CMIP5 that was prepared for the Intergovernmental Panel on Climate Change (IPCC) for their 5th Assessment Report (AR5).

An example of a model-data comparison is shown in Figure Intro-22. To make the comparison graphs a little more readable, you'll note I've used dashed red lines for the model outputs and solid blue lines for the data. I've retained that format throughout the book.

Figure Intro-22 compares the surface temperature data for the Pacific Ocean (from pole to pole) with the multi-model mean (the average) of the dozens of climate model simulations of those sea surface temperatures. The data used in that graph, HADISST, is satellite enhanced from 1982 to present. HADISST is the long-term sea surface temperature reconstruction that is used most often in scientific studies. With that in mind, it must also be noted that HADISST has the lowest warming rate over the past 3+

decades when compared to other sea surface temperature datasets. We'll illustrate and document that in the upcoming Part 2.

Figure Intro-22 covers the period of January 1994 to April 2015. It's obvious the sea surface temperatures of the Pacific made an upswing later in 2014. (That upswing was initially caused primarily by an unusual weather event in the eastern North Pacific, which has been given the comical pet name "The Blob". See General Discussions B and C. The current El Niño ha added to that spike in 2015.) The spike in 1997/98 was caused by the El Niño that occurred then. We'll also discuss El Niños in detail. According to the linear trend, the satellite-enhanced sea surface temperature data for the Pacific Ocean show its surfaces have not warmed in 2+ decades. On the other hand, the climate models show that the surface of the Pacific Ocean should have warmed about 0.37 deg C (about 0.67 deg F) in those 21 years, if (big if) the surface of the Pacific Ocean was warmed by man-made greenhouse gases.

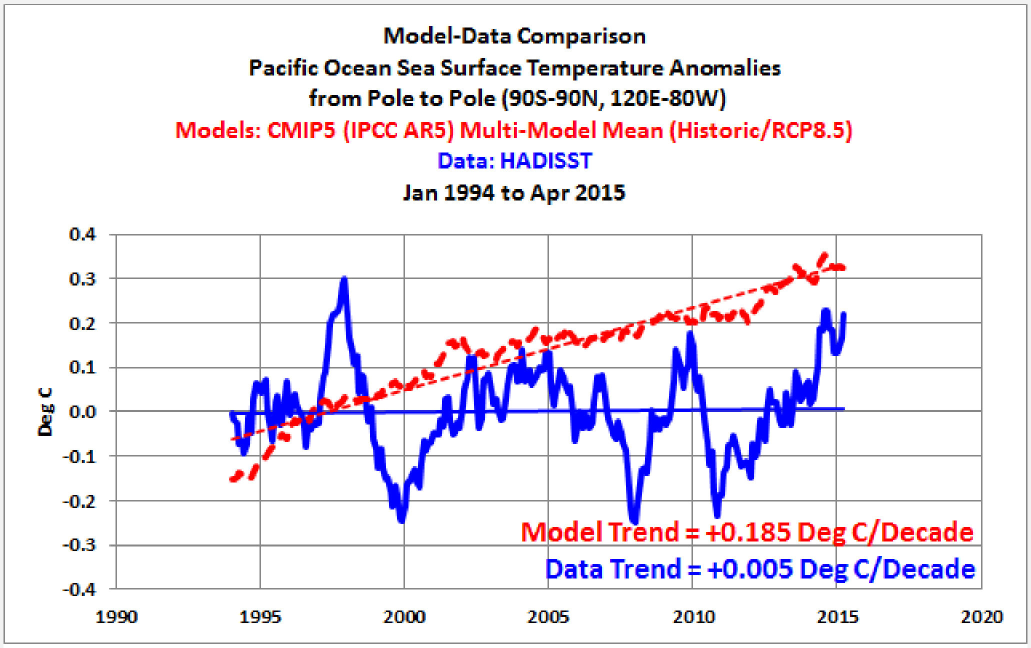
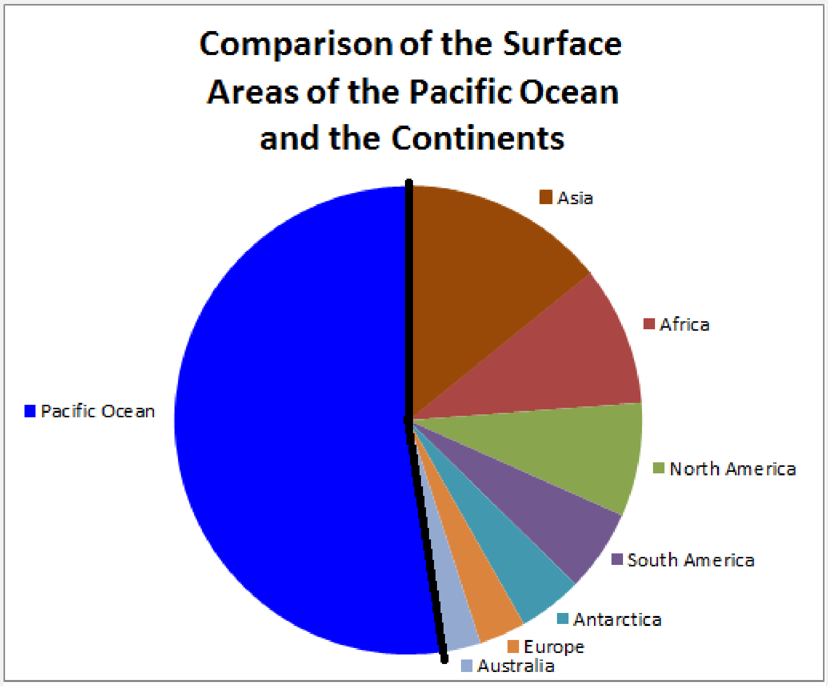


Figure Intro-22

The models didn't do so well there. Now consider that the data and model outputs capture the Pacific Ocean (plus the related portions of the Arctic and Southern Oceans), and that the Pacific by itself covers more of the surface of Earth than all of the continental land masses combined. See the pie chart in Figure Intro-23.



The Pacific Ocean Covers More of the Surface of Earth Than All of the Continental Land Masses Combined

Figure Intro-23

Much of the data and model outputs presented in this book are available to the public in easy-to-use formats from a web tool created by the Royal Netherlands Meteorological Institute (KNMI). That tool is their Climate Explorer. Anyone with internet access and spreadsheet software can confirm what I've presented in this book. In fact, I've provided step-by-step instructions in a couple of blog posts so that you can verify my results. See:

- Very Basic Introduction to the KNMI Climate Explorer
- Step-By-Step Instructions for Creating a Climate-Related Model-Data Comparison Graph

Note: If you're wondering about the large variations in the data in the graph in Figure Intro-22, most of the big upward swings in the Pacific sea surface temperature data are caused by El Niño events, and the most of the large dips are responses to La Niña events.

Why don't the models show the same spikes?

The climate models that are used to simulate past climate and predict future climate cannot properly simulate the ocean-atmosphere processes in the tropical Pacific that cause El Niños and La Niñas to happen, and modelers do not try to reproduce the timing of those events. The models, however, have been programmed to create some large swings in temperatures in the tropical Pacific, but the timing, strength and duration of those variations (and the processes that cause them) are not close to what takes place in the real world. The poorly simulated El Niño and La Niña events in climate models occur randomly with each model run, so, when they are averaged for the model mean, they tend to cancel one another. In other words, averaging all of the random wiggles in the climate model outputs simply smooths them out. [End note.]

This book also presents and discusses the conclusions of peer-reviewed scientific studies and letters to scientific journals that are very critical of climate model performance; that is, those papers present the numerous failings of climate models. I also discussed some of those papers in my book *Climate Models Fail*, but here I've provided more-detailed translations of the science-talk with hope of making them easier to understand.

A PRELIMINARY NOTE ABOUT THE DATA PRESENTATIONS

This book, as you can well imagine, took almost two years to write. I prepared the illustrations as I wrote. Many of the illustrations are time-series graphs with monthly data. So some of those graphs are now out of date by a few months to more than a year.

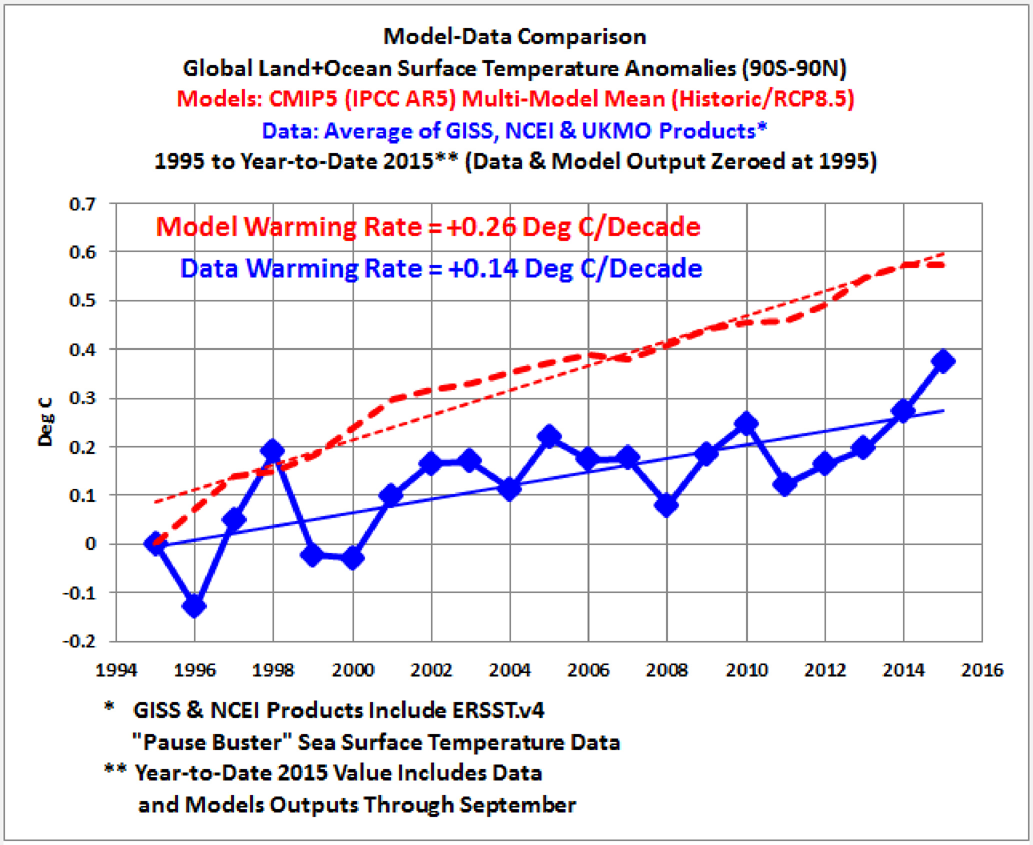


Figure Intro-24

I have updated many of the graphs, however, where the discussions needed a look at fresh data. One of the most current graphs is the model-data comparison of global surface temperature anomalies shown above in Figure Intro-24.

The annual data and model outputs run from 1995 to year-to-date 2015 (2 decades), with 2015 including the months of January through September. In addition to covering a 20+ year period, the start year of 1995 is 4 years after the eruption of Mount Pinatubo. The effects of that eruption, four years later, should only add slightly to the model and data trends. 1995 is also a couple of years before the impacts (the spike) of the 1997/98 El Niño, which should cut down on claims that I've cherry-picked the start year. You'll also note that I've shifted the model outputs and data so that their 1995 values equal zero…for a nice clean presentation. "Zeroing" the data and model outputs does not change the shape of the curves or the warming rates (linear trends) of the data and model outputs; it simply changes when the two curves intersect with zero.

The data are the average of the global surface temperature products from NASA GISS, NOAA NCEI and UKMO. And the GISS and NCEI data include the new ERSST.v4 "pause-buster" sea surface temperature data from NOAA, which we discussed earlier in the Introduction. (See the discussion of Figure Intro-4.) For the models, we're presenting the multi-model mean of the climate models that were used by the IPCC for their 5th Assessment Report, which are stored in the Coupled Model Intercomparison Project, Phase 5 (CMIP5) and available for download at the KNMI Climate Explorer. As we've note a few times so far, the model mean represents the consensus (the groupthink) of the dozens of modeling groups around the world, for how climate should respond to anthropogenic greenhouse gases, if those greenhouse gases were responsible for global warming. For the illustration, the model inputs include historical forcings through 2005 and the worst-case scenario forcings from 2006 to 2015

We can see that the data uptick in 2015 will lead to claims of record-high surface temperatures at the end of the year. We've heard those same claims almost monthly this year. But what those alarmist reports always fail to disclose is, even with the record highs in 2015, global surfaces are warming much slower than the consensus (the groupthink) of the climate modeling groups, which is represented by the model-mean. Over the past 2+ decades, the warming rate of the data is almost half what was predicted by the "state-of-the-art" climate models…even with two of the three datasets using the "overcooked" much-manipulated sea surface temperature data from NOAA.

Alarmists always prefer the surface temperature datasets over lower troposphere temperature data, because the surface data show much more warming than the lower troposphere data. On the other hand, and for the opposite reasons, many skeptics prefer the lower troposphere temperature data. So let's look at the lower troposphere temperature data next.

Figure Intro-25 is similar to Figure Intro-24. It covers the same time period, and includes the same model simulations of surface temperature anomalies, which we're using as a proxy for modeled lower troposphere temperatures. However, for Figure Intro-25, I've presented the average of the RSS and UAH lower troposphere temperature anomaly data. As you'll recall, the lower troposphere is the portion of the Earth's atmosphere that is closest to the surface.

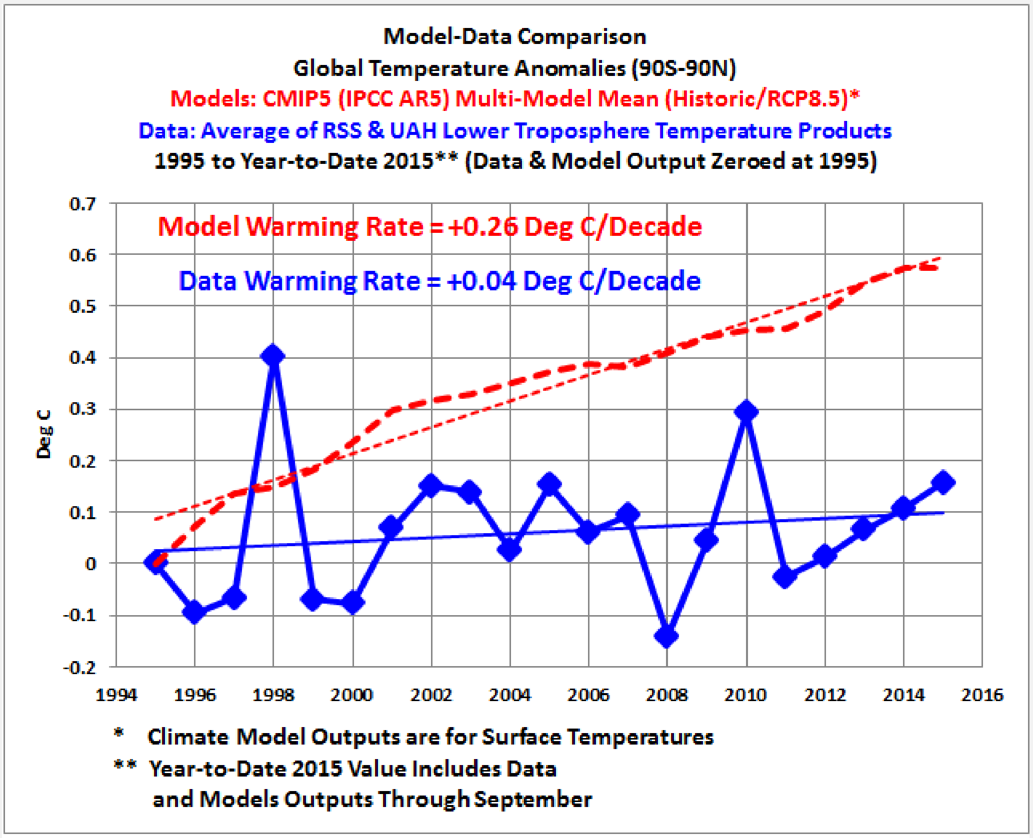


Figure Intro-25

As I've noted before, in a discussion of Earth's climate, the only thing of value that climate models provide is to show how poorly they perform.

MISCELLANEOUS GENERAL DISCUSSIONS

Between the primary sections of this book, I've provided a few general discussions that are relevant to the topics of global warming and climate change. They are:

- Weather Events and Weather-Related Losses Are Not Getting Worse…And the Thirteen Graphs That Helped Launch a Congressional Investigation
- On the Claims of Record-High Global Surface Temperatures in 2014
- On the Reported Record-High Global Surface Temperatures in 2015 – And Will Those Claims Continue in 2016?

OPTIMAL CLIMATE

If we were to believe all of the current alarmism about global warming, we'd conclude that an Earth with warmer surfaces is a bad thing. But is it?

Curiously, for decades, paleoclimatologists (scientists who study Earth's climate before instrument-based records) have used an interesting term for periods when surface temperatures were warmer than today. They call those warm periods "climate optimums". Yet, somehow, now we're being told that any future warming would result in climate catastrophes.

See the 2012 lecture from the University of Arizona website called The climate of the Holocene. It begins (Their boldface):

> *The last glacial maximum (Ice Age) ended about 15 thousand years ago. The most recent glacial retreat is still going on. We call the current period of glacial retreat the* ***Holocene epoch*** *and it continues until present. This page discusses the climate changes within the Holocene Epoch or the current interglacial period from its beginning up until about the year 1900. Prior to the year 1900 most climate changes are considered natural in that the changes could not have been caused by human activity.*

Further down the webpage, it reads (Their boldface):

> *By 5000 to 3000 BC average global temperatures reached their maximum level during the Holocene and were 1 to 2 degrees Celsius warmer than they are today. Climatologists call this period either the* ***Climatic Optimum*** *or the* ***Holocene Optimum****.*

People will often note that the Earth's surface was warmer 5000 to 7000 years ago, yet "Prior to the year 1900 most climate changes are considered natural in that the changes could not have been caused by human activity." That of course prompts a question in the minds of many persons: if it has been warmer in the past without being caused by human activity, how then do we know the current warming is being caused by man-made greenhouse gases?

We don't know for a fact the current warming is being caused by anthropogenic greenhouse gases. We only have the theoretical impacts of CO_2…and the mediocre simulations of Earth's climate in climate models to suggest that the warming was caused by man-made greenhouse gases.

The climate of the Holocene lecture continues (Their boldface. Illustration of frescoes not included.):

> *During the climatic optimum many of the Earth's great ancient civilizations began and flourished. In Africa, the Nile River had three times its present volume, indicating a much larger tropical region. 6,000 years ago the Sahara was far more fertile than today and supported large herds of animals, as evidenced by the Tassili N'Ajjer frescoes of Algeria (right). [Not included.]*
>
> ***You should be familar [sic] with the name, timing, and significance to human civilization for the Climatic or Holocene Optimum.*** *Interestingly, you will notice that events labeled "optimum" correspond to relatively warm periods.*

An earlier Earth with warmer surfaces is associated with the beginning of great civilizations and with their flourishing. An earlier warmer Earth is associated with greater fertility that supports an abundance of life. In the minds of the paleoclimatologists, a warmer climate is a better climate.

Now, according to the current groupthink, a warmer future climate will be a terrible climate. That raises the question: how can the current groupthink say climate will be worse in the future when in the past a warmer climate has proven beneficial? For the answer, we'll return to the earlier quote from Dr. Lindzen:

> *The relation of this sensitivity to catastrophe, moreover, does not even emerge from the models, but rather from the fervid imagination of climate activists.*

MORE ABOUT ME, THE AUTHOR OF THIS BOOK

I've already noted a few times: I am a regular contributor to WattsUpWithThat and I'm probably best known for my well-illustrated data-reliant articles. It's difficult not to find one of my graphs, maps or animations when you perform a Google image search about global surface temperatures, sea surface temperatures, ocean heat content, and the like.

I am an independent researcher, a citizen scientist. That is, I receive no funding for my research other than the occasional and much-appreciated donation or tip from generous persons who visit my blog Climate Observations and WattsUpWithThat. In other words, I am not tied to any political agenda. My primary areas of research are (1) the processes that drive naturally occurring ocean-atmosphere processes like El Niño events and their long-term impacts on global climate, and (2) how poorly climate models perform at simulating climate-related metrics. I was recently included in a group of gentlewomen and gentleman scientists in a blog post by Dr. Judith Curry, Professor and Chair of the School of Earth and Atmospheric Sciences at the Georgia Institute of Technology. See Dr. Curry's blog post More Scientific Mavericks Needed.

I have spent years researching data…and then comparing them to the outputs of climate models…so you don't have to. Please allow me to introduce you to the reasons why many persons are skeptical of the global politics-driven field of climate science, and to show you its realities and its flaws.

MY APOLOGIES

I'm going to repeat a note from my last book *Climate Models Fail*.

My apologies to the conscientious climate scientists who work without agendas to better our understanding of climate, especially those who I have exchanged off-the-record emails with over the years. Please understand, when I am discussing the climate science community in the following pages, I am speaking of those scientists with agendas who, by supporting and encouraging the IPCC's propaganda, have blamed global warming on mankind, without first making the slightest effort to genuinely understand the fundamental processes through which nature contributes to global warming and climate change.

CLOSING TO INTRODUCTION – WE'RE MAKING PROGRESS ON THINGS THAT MATTER

A recent headline from Charlottesville, VA's *The Daily Progress* caught my eye. It read Typhoon roars into south China; tens of thousands evacuated. It wasn't too long ago that the headline might have read, *Typhoon roars into south China; tens of thousands* ***DIE***. If you're not old enough to recall, the 1970 Great Bhola Cyclone reportedly claimed as many as 500,000 lives in what is now Bangladesh. That's only 45 years ago.

We need to continue to help the poor in developing nations adapt to and protect themselves from the ever-changing weather on our lovely planet Earth. We are not doing that by driving hybrid cars and installing solar panels on our roofs…no matter what the marketers of those devices imply or suggest. Your new solar panels, mini-windmills, hybrid cars, etc., may make you feel all warm and fuzzy inside, but they are doing nothing for the poor on this planet who need your help now.

Thank you for reading *On Global Warming and the Illusion of Control*.

NOTE

The following citation is required by the IPCC for the use of their Figure SPM.9:

IPCC, 2013: Summary for Policymakers. In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M.

Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1–30, doi:10.1017/CBO9781107415324.004

GENERAL DISCUSSION 1

Weather Events and Weather-Related Losses Are Not Getting Worse…And the Thirteen Graphs That Helped Launch a Congressional Investigation

Before we get into the meat of this book, there are a bunch of bogus claims about weather that need to be addressed. Let's get them out of the way right from the start.

This chapter presents a very interesting climate-related fact: contrary to what you may have been told or may believe, data indicate that tornados, floods, droughts and hurricanes, and weather-related losses have not increased in recent decades.

As related topics, we'll present two other interesting climate-related facts: (1) that President Obama's Science Advisor misrepresented the testimony of a witness to a Senate hearing when he attempted to downplay that testimony; and (2) a congressman didn't like being told those extreme weather events weren't getting worse so he tried to intimidate and discredit the bearer of the unwanted testimony by initiating an unjustifiable congressional investigation of the witness after the fact. This will give you an idea of why I try to avoid the politics of global warming and climate change.

Last, following those discussions, as supplements, we'll discuss wildfires and heat waves here in the United States.

INTRODUCTION

One of the blatantly obvious scare tactics employed by global-warming activists is to claim weather events—like tornados, floods, droughts and hurricanes, and weather-related losses—are worse now because of the emissions of greenhouse gases, and will become even worse in a future warming world.

But do observations-based data confirm claims that tornados, floods, droughts and hurricanes, and weather-related losses, have increased? Quick answer: No. The data do not confirm increases in the frequency of tornados, floods, droughts and hurricanes. And when the weather-related financial loss data are adjusted for economic-growth factors, they too show no increase.

In fact, the IPCC's Summary for Policymakers, Special Report: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX) reads:

> *There is low confidence in any observed long-term (i.e., 40 years or more) increases in tropical cyclone activity (i.e., intensity, frequency, duration), after accounting for past changes in observing capabilities. It is likely that there has*

> *been a poleward shift in the main Northern and Southern Hemisphere extratropical storm tracks. There is low confidence in observed trends in small spatial-scale phenomena such as tornadoes and hail because of data inhomogeneities and inadequacies in monitoring systems. [3.3.2, 3.3.3, 3.4.4, 3.4.5]*
>
> *There is medium confidence that some regions of the world have experienced more intense and longer droughts, in particular in southern Europe and West Africa, but in some regions droughts have become less frequent, less intense, or shorter, for example, in central North America and northwestern Australia. [3.5.1]*
>
> *There is limited to medium evidence available to assess climate-driven observed changes in the magnitude and frequency of floods at regional scales because the available instrumental records of floods at gauge stations are limited in space and time, and because of confounding effects of changes in land use and engineering. Furthermore, there is low agreement in this evidence, and thus overall low confidence at the global scale regarding even the sign of these changes. [3.5.2]*

That's not to say that the IPCC did not find changes in extreme weather. They note, for example, how cold spells have decreased and heat waves have increased…but logic dictates that those things should to be expected in a warming world regardless of the cause of the warming. And, of course, they discussed the impacts of rising sea levels…seeming to overlook the fact that sea levels have been rising since the end of the last ice age and will continue to rise until we head toward the next ice age.

But again, for tornados, floods, droughts and hurricanes, the evidence wasn't there.

Yet with every weather event, alarmists proclaim they have been made worse by mankind and they will be worse in the future if carbon dioxide emissions continue to increase.

POLITICIANS LOOK TO TESTIMONY AT U.S. CONGRESSIONAL HEARINGS AND SOMETIMES THE TESTIMONY DOES NOT AGREE WITH THEIR BELIEFS

Politicians around the globe hold regular hearings about global warming and climate change. On July 18, 2013, the United States Senate held one titled Climate Change: It's Happening Now. One would think that some of the senators were looking for confirmation that weather has become worse because of human-induced global warming. They were to be disappointed. The three witnesses included Dr. Roger Pielke Jr. - Professor and Director, Center for Science and Technology Policy Research, University of Colorado.

Before we continue, two notes: (1) Roger Pielke, Jr. is a firm believer in the hypothesis that humans are causing global warming through the emissions of greenhouse gases. But because of his testimony that follows, Roger Pielke, Jr. has been labeled a "denier" by alarmists. (2) Roger Pielke, Jr. should not be confused with Roger Pielke, Sr. They are father and son. Pielke, Jr.'s beliefs differ from Pielke, Sr. The father's views on climate science can be found here. [End notes.]

Roger Pielke, Jr.'s written July 18, 2013 senate testimony is here. The initial "Take-Home Points" are (See the original for the footnotes.):

- *There exists exceedingly little scientific support for claims found in the media and political debate that hurricanes, tornadoes, floods and drought have increased in frequency or intensity on climate timescales either in the United States or globally.*[1]
- *Similarly, on climate timescales it is incorrect to link the increasing costs of disasters with the emission of greenhouse gases.*
- *These conclusions are supported by a broad scientific consensus, including that recently reported by the Intergovernmental Panel on Climate Change (IPCC) in its fifth assessment report (2013) as well as in its recent special report on extreme events (2012).*

Here are some specific conclusions, with further details provided below:

- *Globally, weather-related losses ($) have not increased since 1990 as a proportion of GDP (they have actually decreased by about 25%) and insured catastrophe losses have not increased as a proportion of GDP since 1960.*
- *Hurricane landfalls have not increased in the US in frequency, intensity or normalized damage since at least 1900. The same holds for tropical cyclones globally since at least 1970 (when data allows for a global perspective).*
- *Floods have not increased in the US in frequency or intensity since at least 1950. Flood losses as a percentage of US GDP have dropped by about 75% since 1940.*
- *Tornadoes in the US have not increased in frequency, intensity or normalized damage since 1950, and there is some evidence to suggest that they have actually declined.*
- *Drought has "for the most part, become shorter, less frequent, and cover a smaller portion of the U. S. over the last century."*[2] *Globally, "there has been little change in drought over the past 60 years."*[3]
- *The absolute costs of disasters will increase significantly in coming years due to greater wealth and populations in locations exposed to extremes.*

> *Consequent, disasters will continue to be an important focus of policy, irrespective of the exact future course of climate change.*

Roger Pielke, Jr. provided 13 graphs based on observations-based data (not climate models) under 8 categories to support his statements. I've included snapshots of them as my Figures GD-1-1 through GD-1-8. See the original here for the footnotes, with the exception of those for his discussion on drought. I've included his footnotes for drought and highlighted one in my Figure GD-1-8 because it comes into play in a later discussion.

1. **Globally, weather-related losses have not increased since 1990 as a proportion of GDP (they have actually decreased by about 25%).**

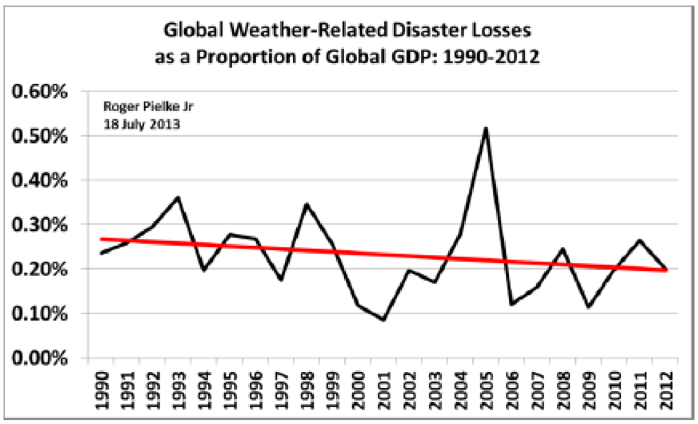


Figure 1. Global weather-related disasters as a proportion of global GDP, 1990-2012. Source of loss data: Munich Re.[8] Source of GDP data: United Nations.[9]

Figure GD-1-1

# # #

Illustration from Pielke, Jr.'s December 11, 2013 Congressional Testimony

2. **Insured catastrophe losses have not increased as a proportion of GDP since 1960.**

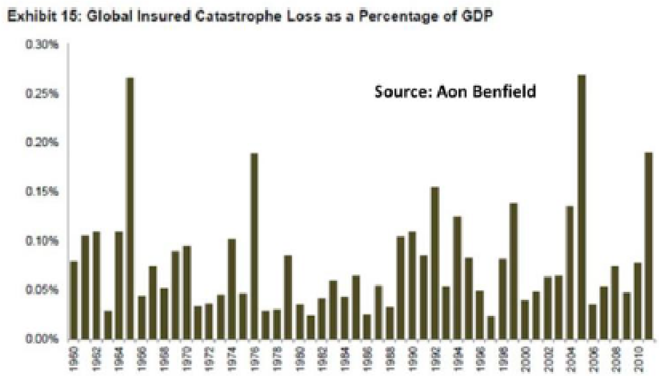


Figure 2. Global insured catastrophe loss as a percentage of global GDP. Source: Aon Benfield.[10]

Figure GD-1-2

# # #

Illustration from Pielke, Jr.'s December 11, 2013 Congressional Testimony

3. **Hurricanes have not increased in the US in frequency, intensity or normalized damage since at least 1900.**

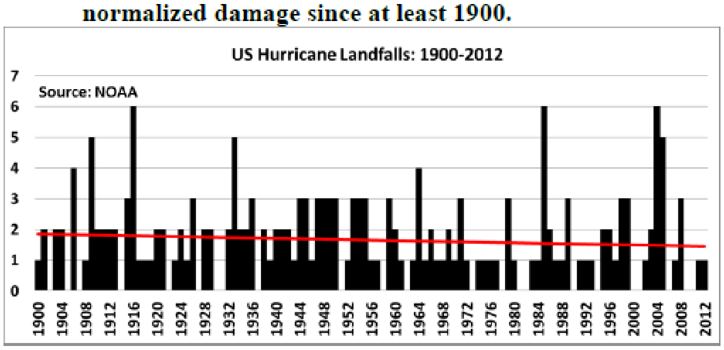


Figure 3a. Number of landfalling US hurricanes from 1900-2012. The red line shows the linear trend, exhibiting a decrease from about 2 to 1.5 landfalls per year since 1900. Source: NOAA.[12]

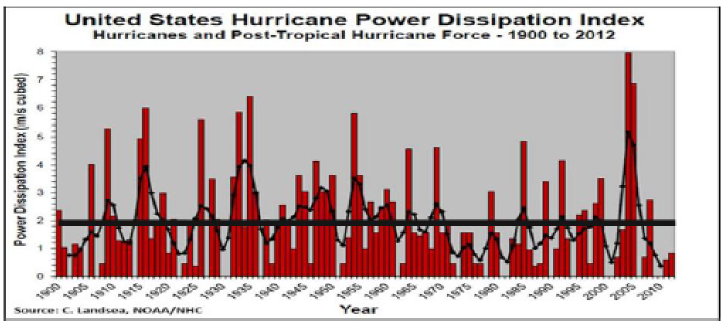


Figure 3b. Intensity of US hurricanes at landfall, 1900-2012 (measured as the summed power dissipation for each year). The heavy black line shows the linear trend. Source NOAA, figure courtesy Chris Landsea, NOAA/NHC.

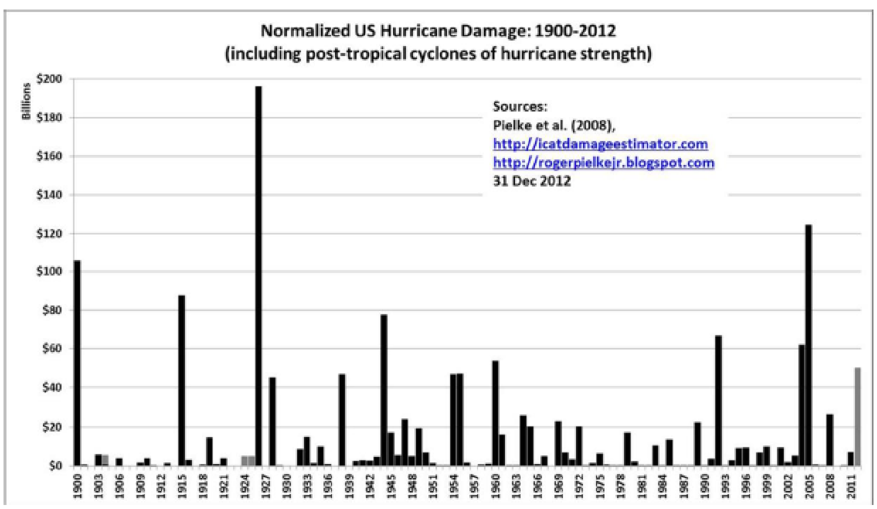


Figure 3c. Normalized US hurricane damage 1900-2012, estimated total damage if each past hurricane season occurred with 2012 levels of development. After Pielke et al. 2008.[13] Note that the figure includes Superstorm Sandy (2012) in gray and placeholders for the three other post-tropical cyclones of hurricanes which made landfall in 1904, 1924 and 1925.

Figure GD-1-3

# # #

Illustration from Pielke, Jr.'s December 11, 2013 Congressional Testimony

4. **There are no significant trends (up or down) in global tropical cyclone landfalls since 1970 (when data allows for a comprehensive perspective), or in the overall number of tropical cyclones.**

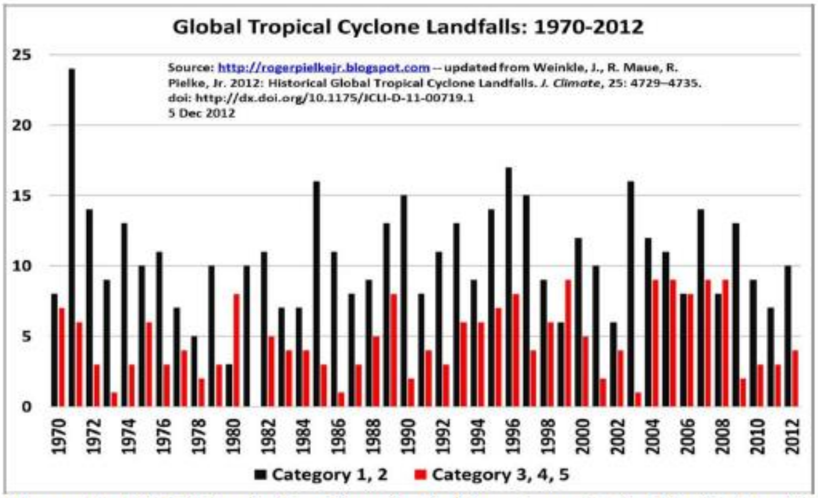


Figure 4a. Global tropical cyclone (called hurricanes in the North Atlantic) landfalls, 1970-2012, after Weinkle et al. 2012.[14]

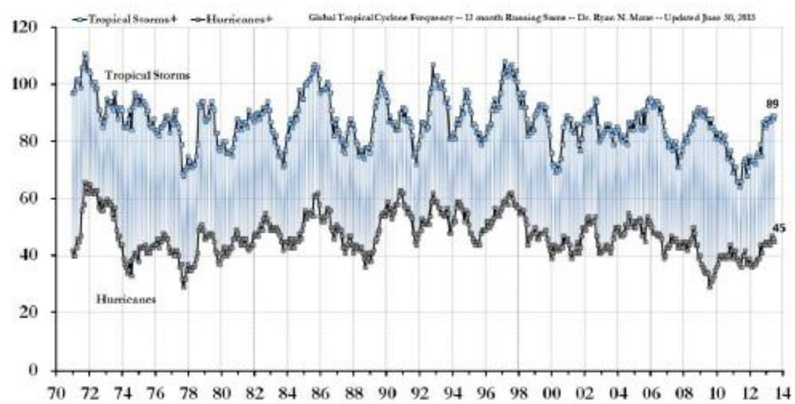


Figure 4b. Total count of tropical cyclones of tropical storm (top curve) and hurricane strength, 12-month running sums 1970 through June 30, 2013. Figure courtesy Ryan Maue.[15]

Figure GD-1-4

# # #

Illustration from Pielke, Jr.'s December 11, 2013 Congressional Testimony

5. **Floods have not increased in the US in frequency or intensity since at least 1950.**

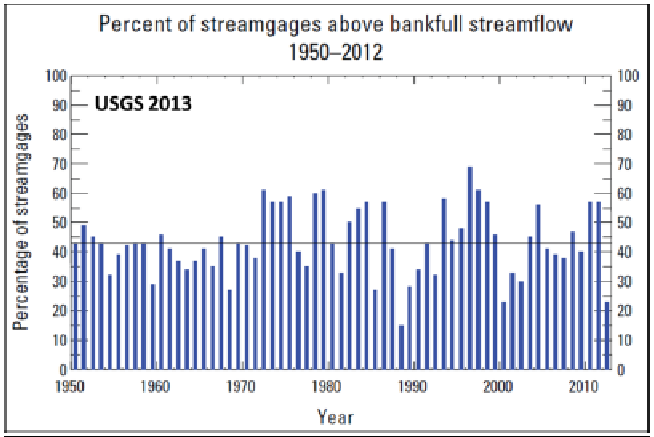


Figure 5. One measure of flood frequency from the USGS, percent of US streamguages above "bankfull streamflow." The USGS explains: "The bankfull streamflow is defined as the highest daily mean streamflow value expected to occur, on average, once in every 2.3 years."[16]

Figure GD-1-5

# # #

Illustration from Pielke, Jr.'s December 11, 2013 Congressional Testimony

6. **Flood losses as a percentage of US GDP have dropped by about 75% since 1940.**

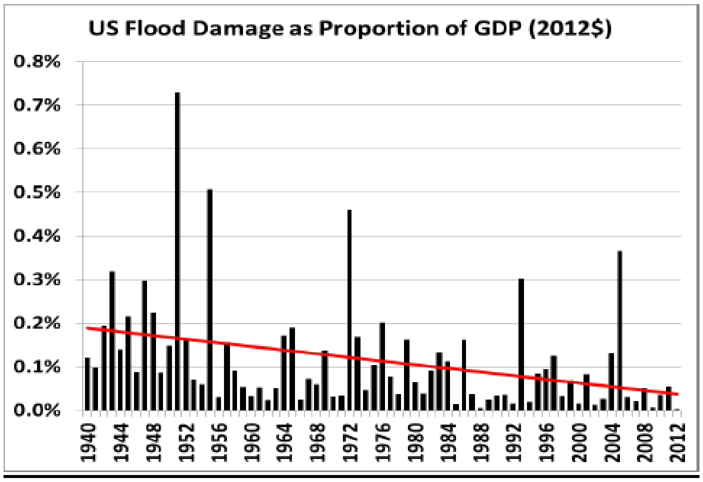


Figure 6. US flood losses as a percentage of US GDP. Annual flood losses have decreased from about 0.2% of US GDP to <0.05% since 1940. Flood loss data from NOAA HIC: http://www.nws.noaa.gov/hic/ GDP data from OMB: http://www.whitehouse.gov/sites/default/files/omb/budget/fy2014/assets/hist10z1.xls[17]

Note: A 2005 peer-reviewed paper examined flood trends around the world and concluded: "observations to date provide no conclusive and general proof as to how climate change affects flood behaviour."[18]

Figure GD-1-6

# # #

<u>Illustration from Pielke, Jr.'s December 11, 2013 Congressional Testimony</u>

7. **Tornadoes have not increased in frequency, intensity or normalized damage since 1950, and there is some evidence to suggest that they have actually declined.**

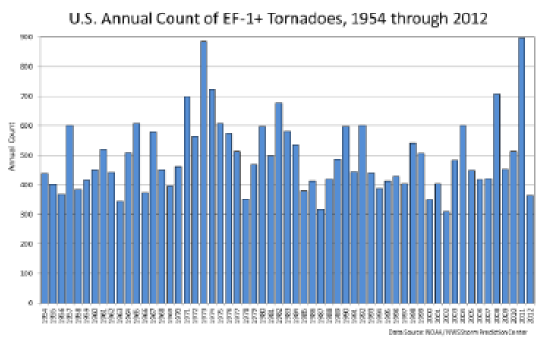


Figure 7a. Count of US tornadoes of at least EF1 strength, 1954-2012.
Source: NOAA, http://www.ncdc.noaa.gov/oa/climate/severeweather/tornadoes.html

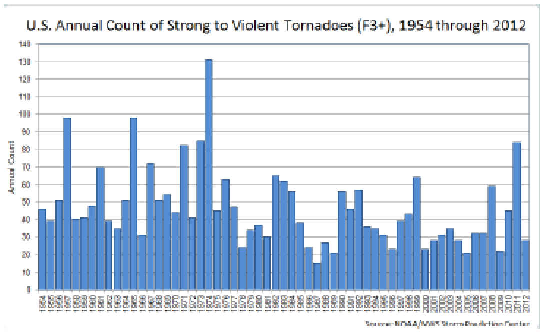


Figure 7b. Count of US tornadoes of at least EF3 strength, 1954-2012.
Source: NOAA, http://www.ncdc.noaa.gov/oa/climate/severeweather/tornadoes.html

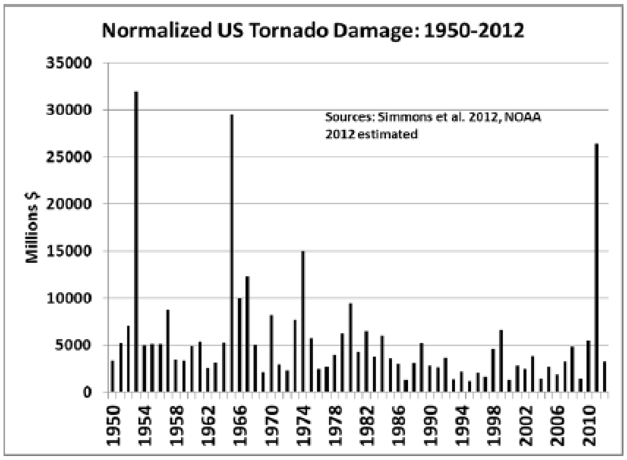


Figure 7c. Normalized US tornado damage, estimated total damage if tornadoes of past years occurred with 2012 levels of development. After Simmons et al. 2012. Note 2012 estimated.[19]

Figure GD-1-7

Illustration from Pielke, Jr.'s December 11, 2013 Congressional Testimony

8. **Drought has "for the most part, become shorter, less frequent, and cover a smaller portion of the U. S. over the last century."[22]**

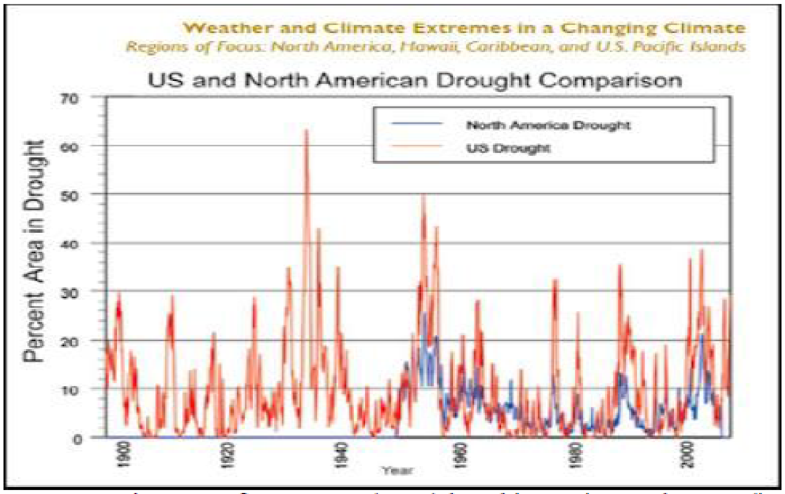


Figure 8. Figure 2.6 from CCSP (2008) has this caption: "The area (in percent) of area in severe to extreme drought as measured by the Palmer Drought Severity Index for the United States (red) from 1900 to present and for North America (blue) from 1950 to present."

Note: Writing in *Nature* Senevirnate (2012) argues with respect to global trends that, "there is no necessary correlation between temperature changes and long-term drought variations, which should warn us against using any simplifications regarding their relationship."[23]

[20] CCSP, 2008: Weather and Climate Extremes in a Changing Climate. Regions of Focus: North America, Hawaii, Caribbean, and U.S. Pacific Islands. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. [Thomas R. Karl, Gerald A. Meehl, Christopher D. Miller, Susan J. Hassol, Anne M. Waple, and William L. Murray (eds.)]. Department of Commerce, NOAA's National Climatic Data Center, Washington, D.C., USA, 164 pp.

[21] CCSP (2008) notes that "the main exception is the Southwest and parts of the interior of the West, where increased temperature has led to rising drought trends."

[22] This quote comes from the US Climate Change Science Program's 2008 report on extremes in North America.

[23] http://www.nature.com/nature/journal/v491/n7424/full/491338a.html

Figure GD-1-8

BOTTOM LINE FOR THIS PORTION

Once again, data disagree with alarmists. There have not been increases in tornados, floods, droughts and hurricanes, or weather-related losses.

Roger Pielke, Jr.'s December 11, 2013 testimony before the Congressional hearing A Factual Look at the Relationship Between Climate and Weather was basically the same and furnished the same graphs.

But let's discuss a few other things that relate to this topic. They highlight the not-so-pleasant side of the politics of the global-warming debate.

THE INITIAL RESPONSE TO ROGER PIELKE, JR'S TESTIMONY CAME FROM PRESIDENT OBAMA'S SCIENCE ADVISOR

As a background item for the next section, the U.S. Senate Subcommittee on Environment and Public Works held a hearing on February 25, 2014 titled "Natural Resource Adaptation: Protecting Ecosystems and Economies". One of the persons to provide testimony was Dr. John Holdren, Director, Office of Science and Technology Policy, Executive Office of the President. Basically, Dr. Holdren is President Obama's science advisor. Dr. Holdren's testimony at that hearing is here.

Dr. Holdren, during the Q&A, categorized Roger Pielke, Jr.'s prior testimony as being outside the "scientific mainstream".

The debate escalated. On February 28, 2014, Dr. Holdren presented a document from the White House titled Drought and Global Climate Change: An Analysis of Statements by Roger Pielke Jr. As could be expected, Roger Pielke, Jr. was not pleased. See his blog post John Holdren's Epic Fail. Based on what Dr. Pielke, Jr. presented in that blog post, it was an epic fail on the part of President Obama's science advisor, Dr. John Holdren.

In that White House document, Dr. Holdren confirmed that he had said Roger Pielke, Jr.'s prior testimony was outside the scientific mainstream.

> *I replied that the indicated comments by Dr. Pielke, and similar ones attributed by Senator Sessions to Dr. Roy Spencer of the University of Alabama, were not representative of mainstream views on this topic in the climate-science community; and I promised to provide for the record a more complete response with relevant scientific references.*

Oddly, Dr. Holdren overlooked the fact that the IPCC agrees with Dr. Pielke, Jr., as noted earlier in this chapter.

More oddly, even though Dr. Pielke, Jr. presented data for tornados, floods, droughts and hurricanes, and weather-related losses, Dr. Holdren only chose to discuss droughts.

Roger Pielke's post notes how Dr. Holdren attributed a quote to Dr. Pielke, Jr., when, in reality, it was not written by Dr. Pielke, Jr. Skeptics see that sort of nonsense from alarmists in blog posts and comments all the time, but we would definitely not expect that type of underhanded climate-science debate tactic coming from a White House science advisor…then again, maybe we would.

The most blatant misrepresentation came when Dr. Holdren stated in his White House document (my brackets):

> *In the rest of this response, I will show, first, that the [Dr. Pielke's] indicated quote from the US Climate Change Science Program (CCSP) about U.S. droughts is missing a crucial adjacent sentence in the CCSP report, which supports my position about drought in the American West.*

The following is Dr. Pielke's "indicated quote from the US Climate Change Science Program (CCSP) about U.S. droughts" (It's hard to miss the superscripts that indicate footnotes.):

> *For the US the CCSP (2008)[20] says: "droughts have, for the most part, become shorter, less frequent, and cover a smaller portion of the U. S. over the last century."[21]*

But as Roger Pielke, Jr., points out in his blog post, he included a footnote in his testimony that specifically addressed the drought in the western U.S. I've highlighted it in my Figure GD-1-8 above. That footnote reads:

> *[21] CCSP (2008) notes that "the main exception is the Southwest and parts of the interior of the West, where increased temperature has led to rising drought trends."*

Once again, the President Obama's science advisor has stooped to questionable debate tactics by making false claims about Dr. Pielke, Jr.'s testimony. Dr. Holdren has undermined his own credibility on climate change- and global warming-related topics.

And that leads us to…

THE CONGRESSIONAL INVESTIGATION, A.K.A. WITCH HUNT

U.S. Congressman Raúl Grijalva (D-AZ) is the ranking member of the House of Representatives Committee on Environment and Natural Resources. On February 24, 2015, Congressman Grijalva sent a letter to the president of Dr. Pielke, Jr.'s university requesting information about Roger Pielke, Jr. A copy of the letter is here. Of course, in an effort to discredit Dr. Pielke, Jr. and his testimony, Congressman Grijalva was looking for "potential conflicts of interest and failure to disclose corporate funding sources in academic climate research". In other words, Congressman Grijalva was looking for anything tying Roger Pielke, Jr. to the fossil fuel industry.

Roger Pielke, Jr. announced the receipt of the letter in his blog post I am Under "Investigation". Dr. Pielke, Jr.'s "crime" according to Congressman Grijalva was:

> *Prof. Roger Pielke, Jr., at CU's Center for Science and Technology Policy Research has testified numerous times before the U.S. Congress[1] on climate change and its economic impacts. His 2013 Senate testimony featured the claim, often repeated, that it is "incorrect to associate the increasing costs of disasters with the emission of greenhouse gases."[2] John Holdren, Director of the White House Office of Science and Technology Policy, has highlighted what he believes were serious misstatements by Prof. Pielke of the scientific consensus on climate change and his (Holdren's) position on the issue[3].*

The footnotes were:

> *[1] - http://rogerpielkejr.blogspot.com/2013/12/house-environment-subcommittee-testimony.html*
>
> *[2] - http://sciencepolicy.colorado.edu/admin/publication_files/2013.20.pdf*
>
> *[3] – John Holdren, "Drought and Global Climate Change: An Analysis of Statements by Roger Pielke Jr." - https://www.whitehouse.gov/sites/default/files/microsites/ostp/critique_of_pielke_jr_statements_on_drought.pdf*

Footnotes 2 and 3 were linked and discussed in this chapter.

Dr. Pielke, Jr. was not alone. The presidents of universities for the six other scholars listed below, whose testimonies before congress did not agree with the consensus, were sent similar letters by Congressman Grijalva:

- Robert C Balling Jr, Arizona State University
- John Christy, University of Alabama
- Judith Curry, Georgia Institute of Technology
- Steven Hayward, Pepperdine University
- David Legates, Department of Agricultural Economics & Statistics, University of Delaware
- Richard Lindzen, Massachusetts Institute of Technology

As far as I know, Congressman Grijalva's little letter-writing campaign was unfruitful. That is, there are no "conflicts of interest" or failures "to disclose corporate funding sources in academic climate research" on the parts of those academics, including Dr. Pielke, Jr.

Congressman Grijalva's witch hunt, however, did have an effect.

Dr. Pielke, Jr. has stopped performing research, and preparing academic papers, and blogging about global warming and climate change, and, he will no longer be testifying at Senate and House of Representative hearings about global warming and climate change. While he had made the decision to move on to other topics, the congressional investigation expedited his transition. See Dr. Pielke, Jr.'s blog post A Quick Guide to Pielke Jr on Climate. There he writes:

> *As friends and colleagues know, I have been on a glide path out of the climate field for a while now, mainly because I have had my say and as a scholar I am ready to move on to more fertile fields of study. This is a decision that I made long before the events of the past week. I had thought I'd just quietly fade away on the issue, but after the events of the past week, that obviously isn't happening!*
>
> *So to be clear: I am no longer conducting research or academic writing related to climate, I am not available for talks, and on the climate issue I have no interest in speaking with reporters or giving testimony before Congress.*

In some respects, Congressman Grijalva's witch hunt was fruitful. It pushed forward Dr. Pielke Jr.'s decision to leave the climate debate. However, as far as I know, Congressman Grijalva's letters to the other presidents of the universities did not result in the other six scholars leaving the fields of climate change and global warming.

Roger Pielke, Jr.'s contribution to the climate debate will be missed. He was, as far as I know, the first researcher to note that there has been a drought of Category 3 or stronger hurricanes making landfall in the United States…since Wilma in November 2005…and that the recent drought of landfalling Category 3 or greater hurricanes is the longest on record. As of this writing, that's almost ten years.

CHAPTER SUMMARY

Roger Pielke, Jr.'s testimony before both the House and Senate in 2013 included graphs of observations-based data (not climate models) that showed no increase in tornados, floods, droughts and hurricanes, or in weather-related losses.

In a White House document, President Obama's science advisor Dr. John Holdren misrepresented Roger Pielke, Jr.'s testimony about drought in an effort to undermine his entire testimony. Unfortunately for Dr. Holdren, with that act, he has undermined his own credibility, not Dr. Pielke, Jr.'s.

Apparently frustrated by the testimony from academics who did not agree with his beliefs about global warming and climate change, U.S. Congressman Raúl Grijalva (D-AZ) attempted to intimidate those scholars with letters to the presidents of their respective universities. The letter to the president of Dr. Roger Pielke, Jr.'s university had its desired effect. Dr. Pielke, Jr. pushed forward his decision to leave climate-related research.

Dr. Holdren's misrepresentation of Dr. Pielke, Jr.'s testimony and Congressman Raúl Grijalva's witch hunt are two examples of the politics of global warming and climate change at their worst.

POSTSCRIPT

Let's add wildfires and heat waves in the United States to the discussion.

Wildfires have been in the news recently because of the (naturally caused) drought in the western United States and the wildfires taking place there. But are you aware that there has been a sharp decline in the number of acres consumed in the U.S. by wildfires since the 1920s and '30s?

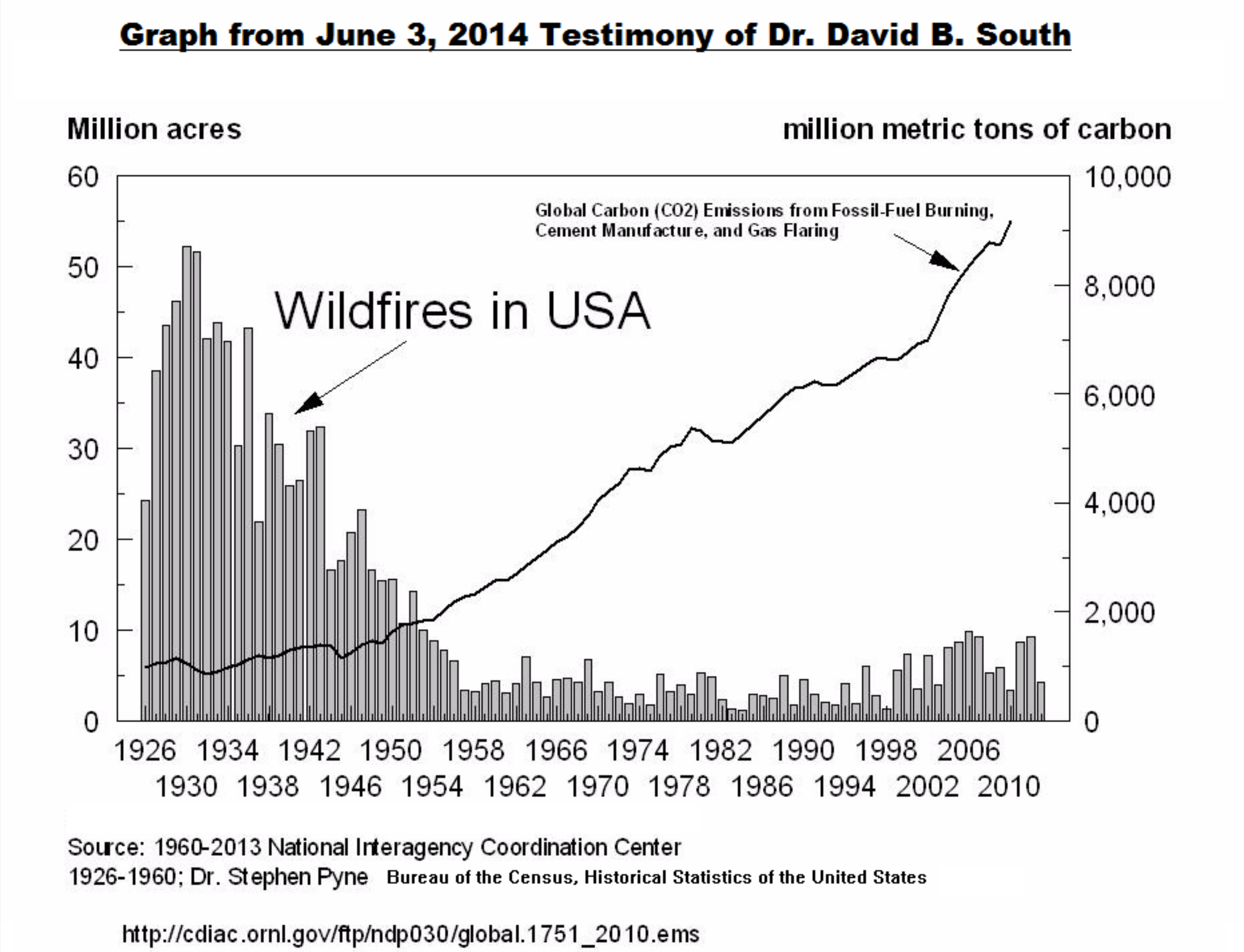


Figure GD-1-9

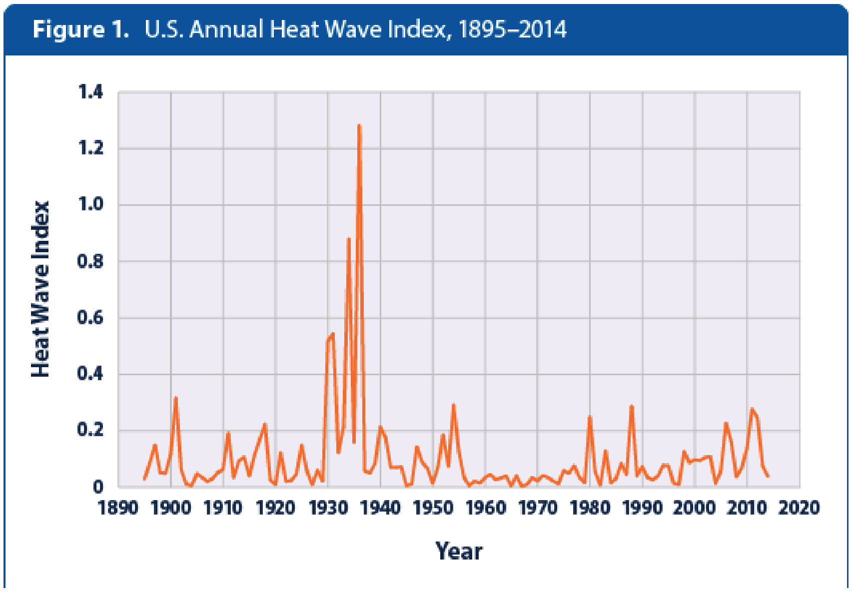
Figure GD-1-9 is Figure 1 from the testimony of Dr. David B. South (professor emeritus) Auburn University, School of Forestry and Wildlife Sciences: Human Activity, more so than Climate Change, Affects the Number and Size of Wildfires at the June 3, 2014 U.S. Senate Subcommittee on Green Jobs and the New Economy hearing entitled, "Farming, Fishing, Forestry, and Hunting in an Era of Changing Climate". Dr. Smith writes:

> *There is a well-known poem called the "Serenity prayer." It states "God, grant me the serenity to accept the things I cannot change, the courage to change the things I can, and wisdom to know the difference." Now that I am 63, I realize I can't change the behavior of the media and I can't change the weather. Early in my career I gave up trying to get the media to correct mistakes about forest management and to avoid exaggerations. I now concentrate on trying to get my colleagues to do a better job of sticking to facts; I leave guesses about the future to others.*
>
> *Untrue claims about the underlying cause of wildfires can spread like "wildfire." For example, the false idea that "Wildfires in 2012 burned a record 9.2 million acres in the U.S." is cited in numerous articles and is found on more than 2,000 web sites across the internet. In truth, many foresters know that in 1930, wildfires burned more than 4 times that amount. Wildfire in 2012 was certainly an issue of concern, but did those who push an agenda really need to make exaggerated claims to fool the public?*
>
> *Here is a graph showing a decreasing trend in wildfires from 1930 to 1970 and an increasing trend in global carbon emissions. If we "cherry pick" data from 1926 to 1970 we get a negative relationship between area burned and carbon dioxide. However, if we "cherry pick" data from 1985 to 2013 we get a positive relationship. Neither relationship proves anything about the effects of carbon dioxide on wildfires since, during dry seasons, human activity is the overwhelming factor that determines both the number and size of wildfires.*

The remainder of Dr. South's testimony is just as enlightening.

The last topic in this chapter is heat waves. Figure GD-10 is an illustration titled "U.S. Annual Heat Wave Index, 1895-2014". It clearly shows that U.S. heat waves were much worse in the 1930s than they have been in recent decades. You'll also note that the graph was not prepared at some website run by climate skeptics. The graph is from the High and Low Temperatures webpage, which is part of the Climate Change web series prepared by the U.S. Environmental Protection Agency (EPA).

Heat Wave Index Graph from EPA Website



Source: http://www3.epa.gov/climatechange/science/indicators/weather-climate/high-low-temps.html

Figure GD-1-10

The caption for the graph reads:

> *This figure shows the annual values of the U.S. Heat Wave Index from 1895 to 2014. These data cover the contiguous 48 states. Interpretation: An index value of 0.2 (for example) could mean that 20 percent of the country experienced one heat wave, 10 percent of the country experienced two heat waves, or some other combination of frequency and area resulted in this value.*
>
> *Data source:* Kunkel*, 2015* [5]

Bottom line: we can add wildfires and heat waves in the U.S. to the long list of phenomena that are not getting worse due to global warming.

1 - FUNDAMENTALS OF GLOBAL WARMING AND CLIMATE CHANGE

This section presents 27 chapters that introduce the theory behind man-made global warming and climate change, in very basic terms, along with a number of related topics. I have not included a history of the theory of man-made global warming, as I don't believe it really contributes to the discussion. I also have not included every argument for and against the topics included in each chapter. These are introductions.

1.1 – Our Planet Was Poorly Named

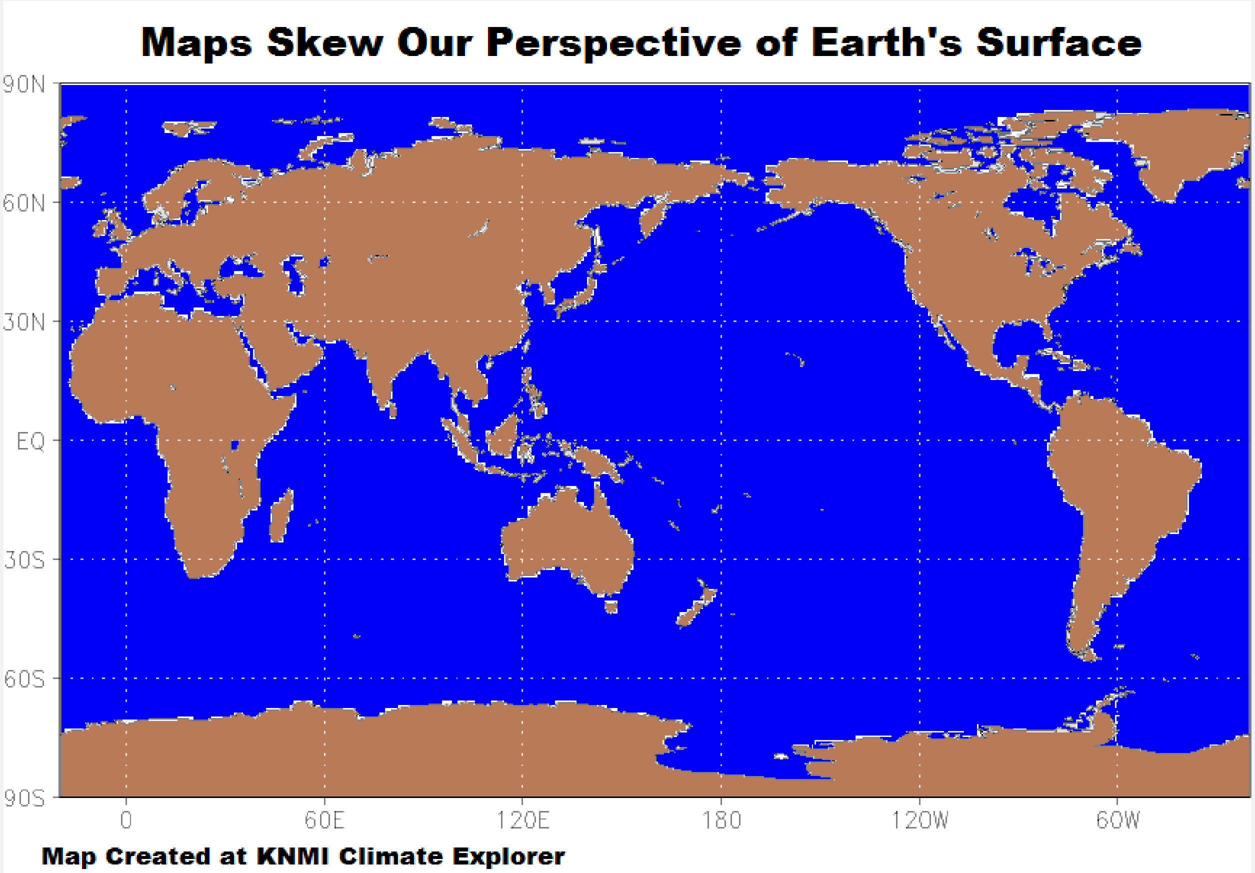
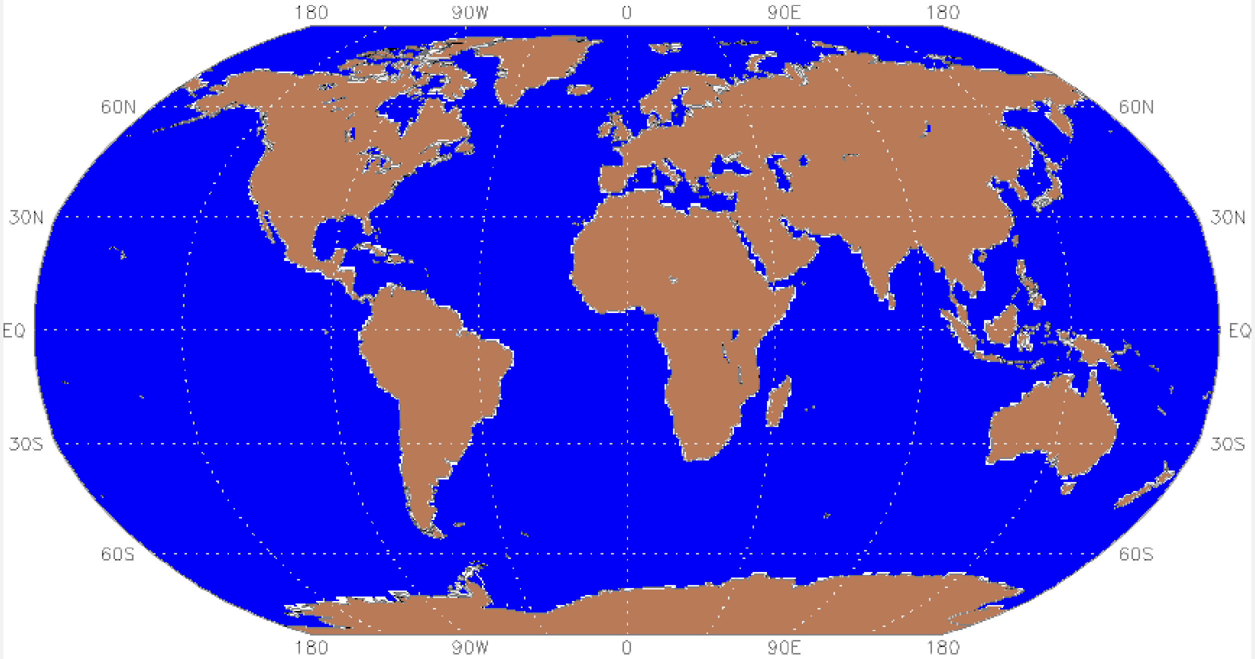


Figure 1.1-1

Looking at a typical projection of the Earth's surface on a rectangular map, Figure 1.1-1, we lose our perspective of our planet. The mid-to-high latitudes of the Northern Hemisphere contain more land than in the Southern Hemisphere, and because the high latitudes are exaggerated in the map, it skews our perspective. At the other end of the globe, Antarctica is the fifth largest continent on the planet, or the third smallest depending on your point of view, but it looks monstrously large on those projections. Similarly, the Arctic Ocean looks large in Figure 1.1-1. But the Arctic Ocean is the smallest ocean on Earth, covering only about 3% of the surface of the Earth (See the NOAA webpage here.), but it too looks much larger on the map.

Different presentations like a Robinson Projection help, Figure 1.1-2, but they are still biased toward showing land surfaces.

Robinson Projections Are an Improvement



Map Created at KNMI Climate Explorer

Figure 1.1-2

As Arthur C. Clarke wrote back in 1990:

> *How inappropriate to call this planet Earth when clearly it is Ocean.*

Maybe when Arthur C. Clarke wrote that he was looking at an image of the Earth when centered over the Pacific Ocean. If that was his perspective, he would have seen ocean with only small specks of continental land masses and islands. See Figure 1.1-3.

Few of us have globes anymore, but you can reproduce the image in Figure 1.1-3 easily. Open Google Earth on your computer, and enter the coordinates of 0N, 160W (0, -160) in the “Fly to” field. Then zoom out. You have a wonderful image of the Pacific Ocean, with very little land mass visible. To the northeast, there’s the west coast of North America. The shoreline of Asia is just visible in the northwest. Papua-New Guinea is to the west, and south of it is part of Australia, with New Zealand off its east coast. Now try the coordinates of 24S, 135W (enter -24, -135 in the “Fly to” field).

That's just north of the South Pacific island of Mangareva. Zoom out once again until you can see the entire globe. There's even less land mass in the image.

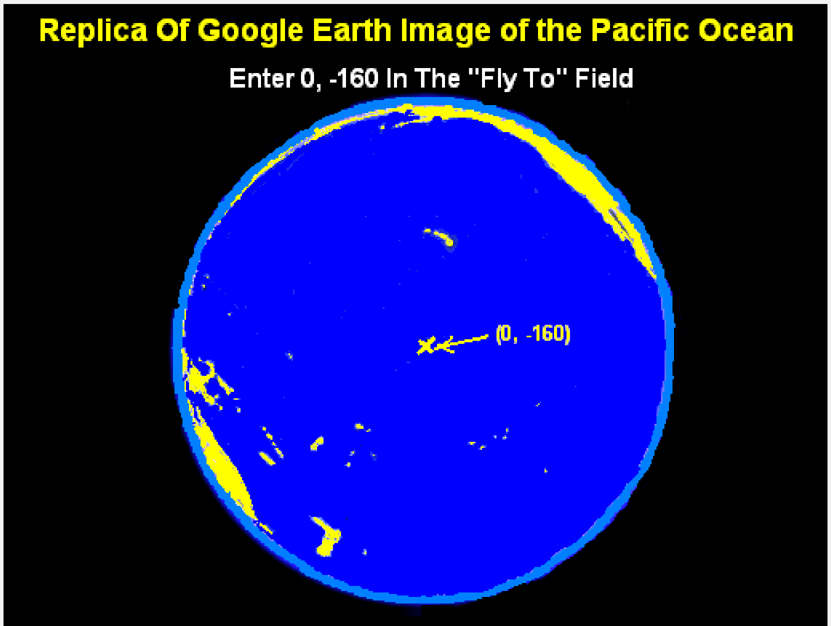


Figure 1.1-3

# # #

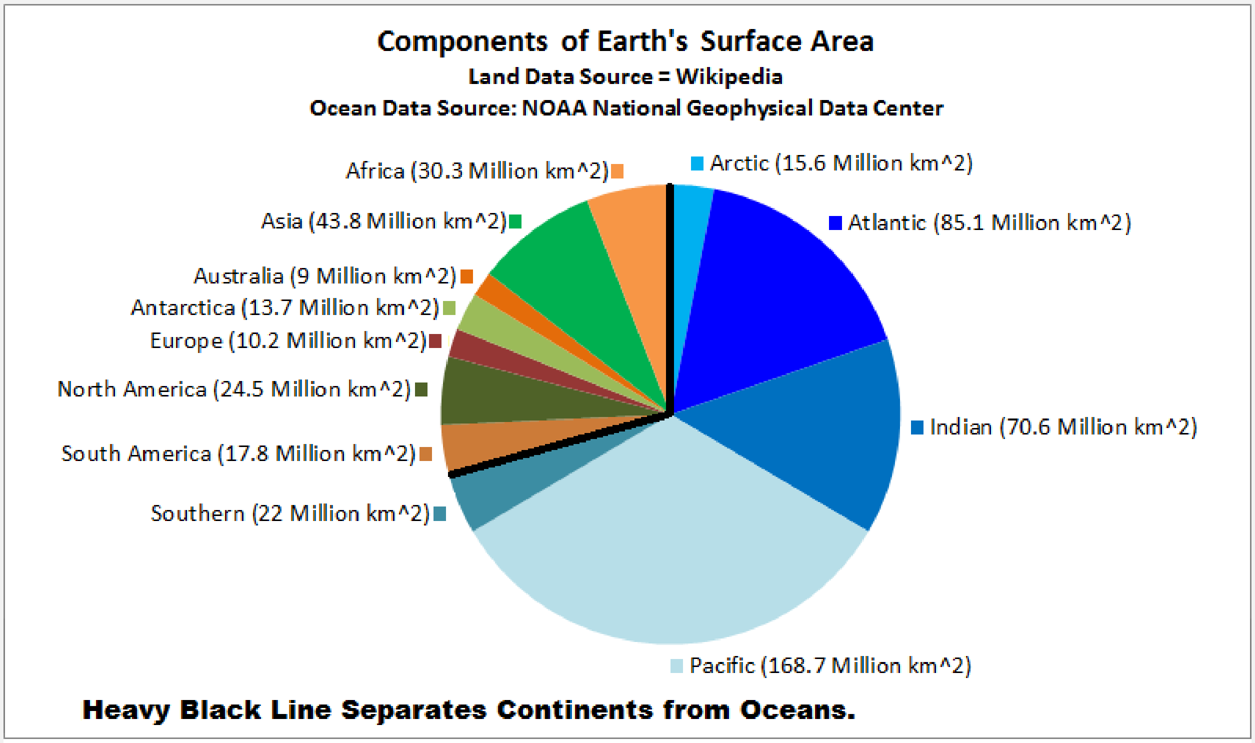


Figure 1.1-4

The oceans cover more than twice the surface of the Earth than the continental land masses. I've broken the surface areas of the oceans down into their individual ocean basins and compared them to the surface areas of the continents in Figure 1.1-4. We live on land surfaces but the vast majority of the planet is covered by the oceans. The Pacific Ocean alone covers more of Earth's surface than all of the continental land masses combined.

Because almost all residents on Earth live on the land surfaces, our perspective of our lovely planet is skewed. When we think of the Earth, we think of land. But the Earth is covered mostly by oceans. The oceans dictate surface temperatures on land. Most of the moisture in the atmosphere comes from the oceans, about 90%. The oceans temper the seasons, preventing the land surfaces from becoming too cold in the winter and too warm in the summer.

The surface temperatures of the oceans are also very important to some climate modelers. They tune the atmospheric portion of their climate models using sea surface temperature data from the recent warming period, the mid-1970s to the turn of the century. Unfortunately for the modelers, when they then have the models try to simulate Earth's recent climate, the atmospheric components of the models also fail because the models cannot simulate the coupled ocean-atmosphere processes that govern sea surface temperatures.

Because the oceans are not cooperating with the hypothesis of man-made global warming (and they definitely are not cooperating), and because it can be shown that naturally occurring, sunlight-fueled ocean processes are responsible for most of their warming (this will be discussed later in this book), the hypothesis of human-induced global warming is fatally flawed.

The modelers have, however, tuned, tweaked, adjusted, biased, etc., their models so that the land surfaces, globally, warm at a rate that is similar to what has been observed in recent decades. But, as shown in Figures 1.1-5 and 1.1-6 (same as Figures Intro-5 and Intro-6), in order to do that, they've had to double the observed warming rate of the ocean surfaces.

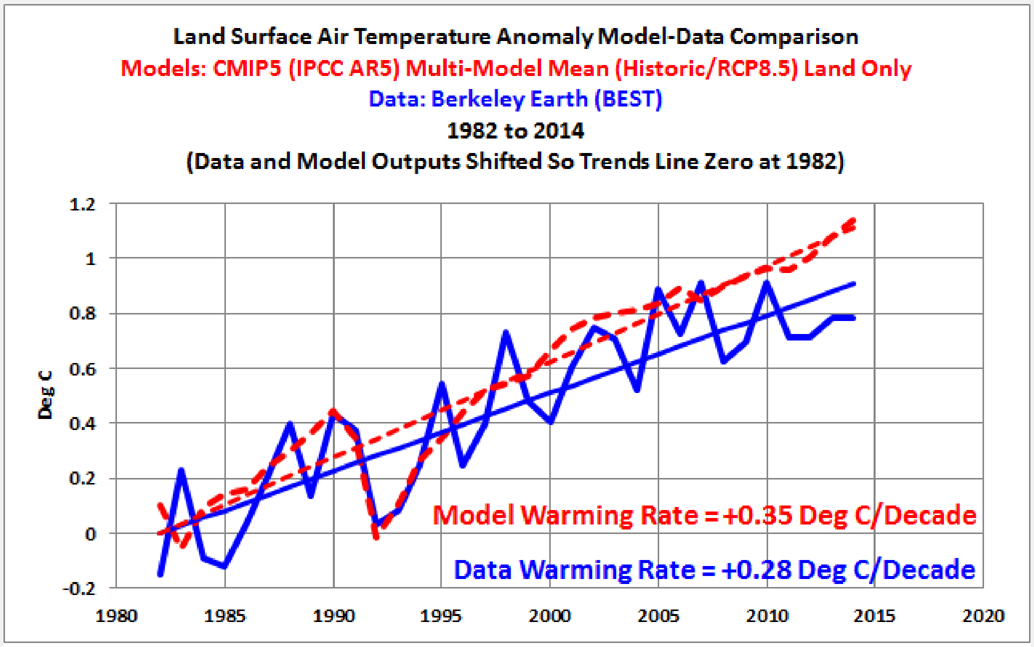
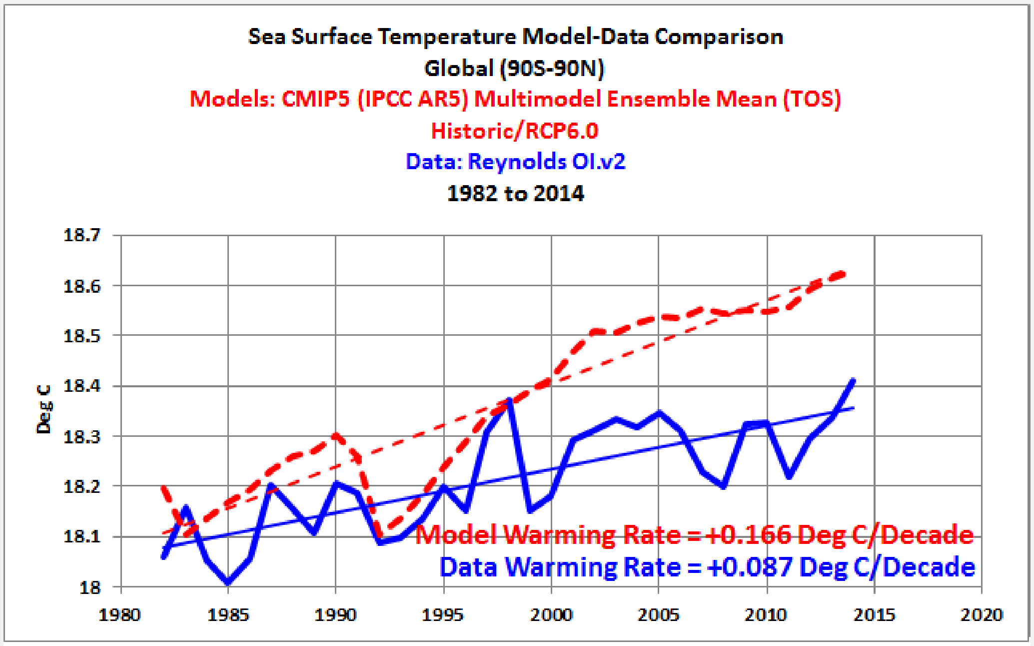


Figure 1.1-5

# # #



Climate Models Almost Double The Observed Warming Rate Of The Global Ocean Surfaces. Climate Scientists Are Also Still Looking For About 50% Of The Heat That Is Supposed To Be Stored In The Oceans. The "Missing Heat" And Doubling Of Ocean-Surface Warming Suggest The Model Sensitivities Are At Least Two-Times Too High.

Figure 1.1-6

In other words, climate modelers are focused on land surfaces and the atmosphere, when, in reality, climate on this planet is dictated by the oceans.

1.2 – What is Global Warming?

The term "global warming" has come to mean the warming of our planet Earth (the surface, the lower atmosphere, and the oceans to depth) that has been caused by, and will be further enhanced by, the emissions of man-made greenhouse gases. No one bothers calling it *man-made* global warming or *anthropogenic* global warming or *human-induced* global warming anymore. Whenever a news report or article uses the term global warming, everyone now assumes they're talking about the hypothetical man-made kind of warming.

There are many possible reasons why global warming has occurred over the past few decades, some of which are natural, but the primary focus of research has been on the consequences of increased emissions of carbon dioxide into the atmosphere that result from the burning of fossil fuels.

Graphs that show global land plus ocean surfaces warming since pre-industrial times are commonplace. Figure 1.2-1 shows the annual global land+ocean surface temperature anomalies, based on the UKMO HadCRUT4 reconstruction, from its start year in 1850 through to 2014. Based on the linear trend, global surfaces are warming at a not-very-alarming long-term rate of about 0.06 deg C/decade (about 0.10 deg F/ decade)…for a total warming of less than 0.8 deg C (about 1.4 deg F) since 1880.

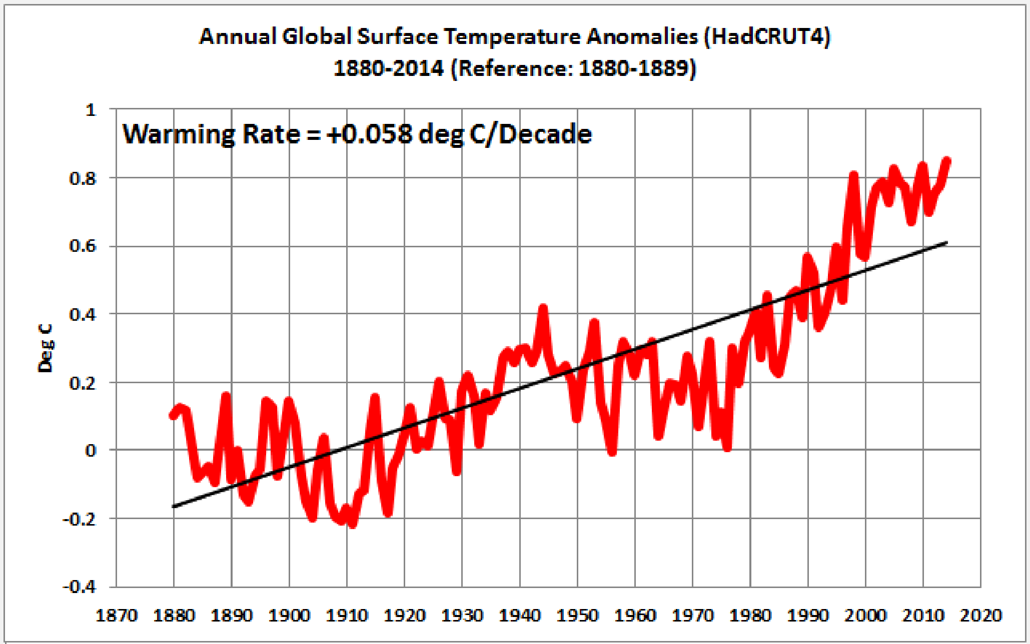


Figure 1.2-1

The linear trend line also helps to illustrate that the warming was not continuous. Initially, there is a period of cooling followed by a period of warming until the mid-1940s. Then the cycle repeats itself with a period of cooling until the mid-1970s, followed by a warming period. Because the rates of warming during the two warming periods are greater than the cooling rates during the two cooling periods, there is a positive warming trend.

That leaves us with a very basic question. Should we expect another multidecadal cooling period, or at least a slowdown lasting for a couple of decades, before another warming period? Rephrased, would we expect the multidecadal (approximately 60-year) cycle to repeat itself?

Many persons believe the cycle will repeat into the future. The climate modelers do not. Their models have been tuned to extend (and amplify) the warming from the more recent higher-than-average warming period out into the future, without accounting for the cyclical nature of global warming. If the cycle continues into the future, then the climate models have simulated too much warming…way too much warming.

THE RATE OF WARMING IS SO SMALL WE HAVE TO BE TOLD GLOBAL WARMING IS HAPPENING. WE CAN'T SENSE IT.

In the Introduction, I noted we have to be told global warming is occurring…that we as individuals would not be able to sense that global surface temperatures have warmed. Daily and seasonal variations in local temperatures are so great that we'd never notice the slight change in global surface temperatures we've experienced since the mid-1970s. It's only about 0.7 deg C or 1.3 deg F (based on the linear trend), and it's occurred over a 40-year period.

Think about how great the temperature variations are at your home: over the course of every year…and daily. Here are examples from a widely referenced dataset.

In the two graphs in Figure 1.2-2, the increase in annual global surface temperature (red curves) since 1880 (same red curve as in Figure 1.2-1) is compared to daily maximums (orange curves) and minimums (dark green curves) for the Central England Temperature dataset, during that same timeframe. The top graph shows the three datasets in deg C, while the bottom graph shows them in deg F.

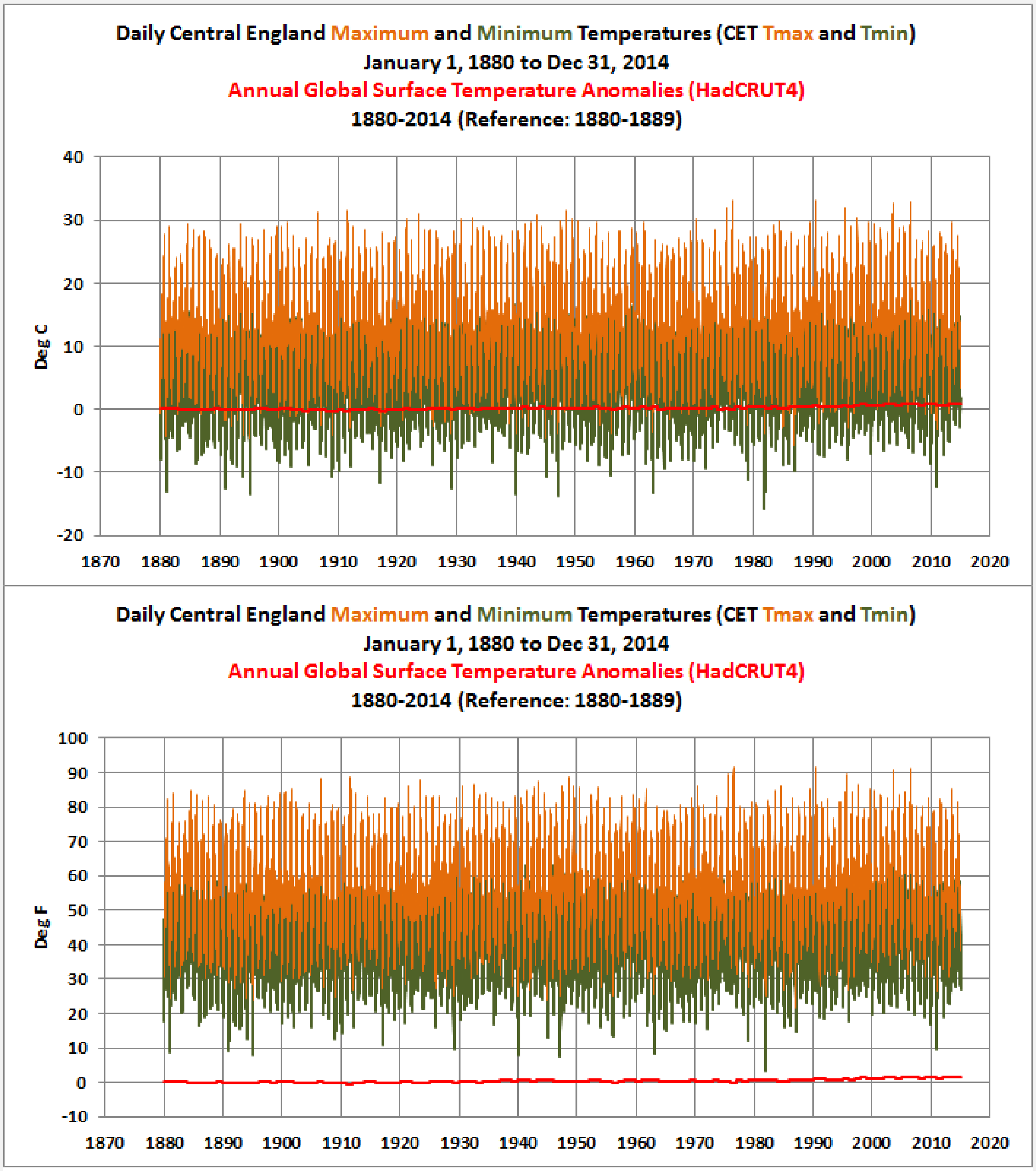


Figure 1.2-2

The UKMO Central England Temperature (a.k.a. HadCET or simply CET) dataset is the longest continuous temperature record in the world. It is supported by the 1992 Parker et al. paper A new daily Central England Temperature series. As its name suggests, it is not based on a temperature record at one specific location but rather a group of locations in Central England.

Daily Central England maximum (Tmax) and minimum (Tmin) temperature data are available from the KNMI Climate Explorer, specifically the Daily climate indices webpage, starting in 1878.

The minimums of the green curves in Figure 1.2-2 above show the lowest temperatures reached each year, and the maximums are the highest annual temperatures. Obviously, the range in temperatures that Central England sees every year dwarfs the rise in global surface temperatures.

Now let's consider the daily change in temperature, from minimum to maximum.

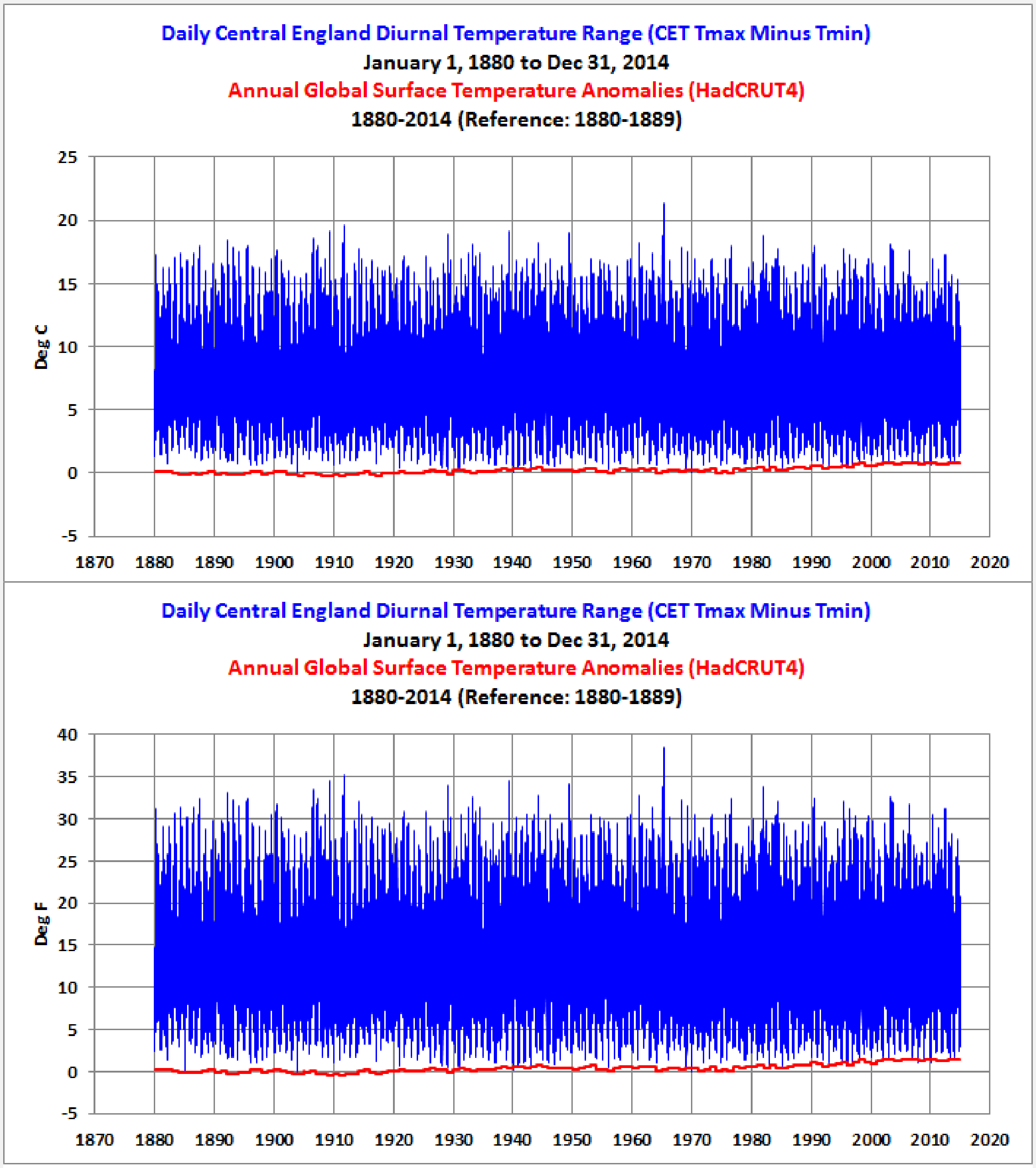


Figure 1.2-3

Using the Central England Temperature data again for example, we can determine what climate scientists call the *diurnal temperature range* by subtracting the daily minimum temperatures from the daily maximums. See Figure 1.2-3. The global surface temperature anomalies are also included as a reference. As shown, there can be very large swings in daily temperatures.

As I wrote earlier, because the daily and seasonal variations in temperature where we live are so great, it's very unlikely that we would be able to sense that global surface temperatures have warmed. We have to be told. I suspect that's why most people around the world rank global warming low on their list of priorities. See the MyWorld2015.org poll The United Nations Global Survey for a Better World.

Some readers may recall a similar presentation by Dr. Richard Lindzen, Alfred P. Sloan Professor of Meteorology (emeritus) at the Massachusetts Institute of Technology, in one of his many lectures on global warming. Yes, the idea for this topic came from his November 17, 2009 talk at Oberlin College. See the YouTube video here. It's a wonderful lecture.

BE WARY HOW THE TERM GLOBAL WARMING IS BEING USED

Global warming can mean different things to different people. As a result, we have to be careful about how the term is used. Let's assume a reporter is interviewing a climate scientist…but unknown to the reporter, the scientist is a skeptic.

If the reporter were to ask: *Do you believe in global warming?*

And if the scientist answered: *Yes. Numerous datasets indicate the Earth has warmed since the start of the 20th Century.*

That answer makes the scientist part of the consensus, the groupthink.

And if the reporter were to ask: *Do you believe that mankind has contributed to global warming?*

Scientist's answer: *Yes. Mankind has contributed to global warming in many ways.*

The scientist didn't specify what those "many ways" were. If the reporter was to stop there, the scientist would be thought to be a part of the groupthink.

But if the reporter asked: *Do you believe that mankind is the primary cause of global warming and that future warming will lead to catastrophe?*

Suppose now the scientist were to answer: *Based on my research and detailed understanding of the data, climate models and their uncertainties, my answer is no.*

For that answer, the scientist would likely be branded a heretic.

Different interpretations of the term global warming can also lead to questionable results in polls.

Bottom line: Always be wary of term global warming and how it is being used. Is the author discussing the fact that the surface of the Earth has warmed? Is he or she discussing naturally caused warming or human-induced global warming?

ACCORDING TO A WELL-KNOWN AND WELL-RESPECTED CLIMATE SCIENTIST, "…NO PARTICULAR ABSOLUTE GLOBAL TEMPERATURE PROVIDES A RISK TO SOCIETY…"

Every now and then, during the discussion of a global warming-related topic, a climate scientist—a member of the consensus—will make an amazing statement…or two. Examples can be found in a blog post by Dr. Gavin Schmidt, Director of the Goddard Institute of Space Studies. Dr. Schmidt wrote the following in his December 2014 blog post Absolute temperatures and relative anomalies, at RealClimate. (Blog post archived here.) Dr. Schmidt was attempting to downplay the fact that there is a large range (about 3 deg C or about 5.4 deg F) in the absolute global surface temperatures produced by the climate models stored in the CMIP5 archive, which is roughly 3 times the warming we've experienced since pre-industrial times. Dr. Schmidt states, where GMT is global mean temperature (my boldface and my brackets):

> *Most scientific discussions implicitly* ***assume*** *that these differences [in modeled absolute global surface temperatures] aren't important i.e. the changes in temperature are robust to errors in the base GMT value, which is true, and perhaps more importantly, are focussed on the change of temperature anyway, since that is what impacts will be tied to.* ***To be clear, no particular absolute global temperature provides a risk to society, it is the change in temperature compared to what we've been used to that matters****.*

See, I told you. That paragraph includes two memorable statements.

First: "…it is the change in temperature compared to what we've been used to that matters".

Well, we're "used to" wide variations in surface temperature every day, and "used to" even greater changes each year.

Second: "To be clear, no particular absolute global temperature provides a risk to society…"

I would hazard a guess that many of you are now wondering why politicians around the globe are concerned about global warming. If the absolute global mean temperature today provides no "risk to society", and if an absolute global mean temperature that's 2.0 to 4.0 deg C (3.6 to 7.2 deg F) higher than today provides no "risk to society", then what's all the hubbub about? Based on Dr. Schmidt's statement, should the priority then be adaptation to weather and rising sea levels, not reductions in greenhouse gas emissions?

1.3 – The Primary Metric Used to Describe Global Warming is Global Surface Temperature Anomalies

From the beginning, the Intergovernmental Panel on Climate Change has focused on global land+ocean surface temperatures. See the Summary for Policymakers of the IPCC's First Assessment Report published in 1990. Under the heading of "Introduction: what is the issue?" the IPCC writes (my boldface):

> *There is concern that human activities may be inadvertently changing the climate of the globe through the enhanced greenhouse effect, by past and continuing emissions of carbon dioxide and other gases which will cause the temperature of the* ***Earth's surface*** *to increase – popularly termed the "global warming' If this occurs, consequent changes may have a significant impact on society.*

The IPCC has broadened their concerns with time, but the primary focus is still global surface temperatures. In fact, the primary goal of the continued efforts of reducing greenhouse gas emissions is to limit global surface warming to an economist-proposed 2-deg C limit. (Refer to the Introduction under the heading of THE EVOLUTION OF THE GLOBAL WARMING MOVEMENT.)

THE ATTEMPTS TO SHIFT FROM SURFACE TEMPERATURES TO OTHER METRICS

The recent slowdown in the warming of surface temperatures (better said, the growing difference between models and data) has caused many persons (alarmists) to focus on other metrics, like ocean heat content, to show that global warming continues even though surface warming has not accelerated as shown by the models. The alarmists generally present that warming using units that make the warming seem impressive—Joules times 10 to the 22nd power or Joules*10^22—which are great big numbers with 22 zeroes. See Figure 1.3-1, which is a presentation of global ocean heat content data from NOAA's National Oceanographic Data Center (NODC), for the depths of 0-2000 meters (about 0-6560 feet).

Sample Ocean Heat Content Illustration from the NODC

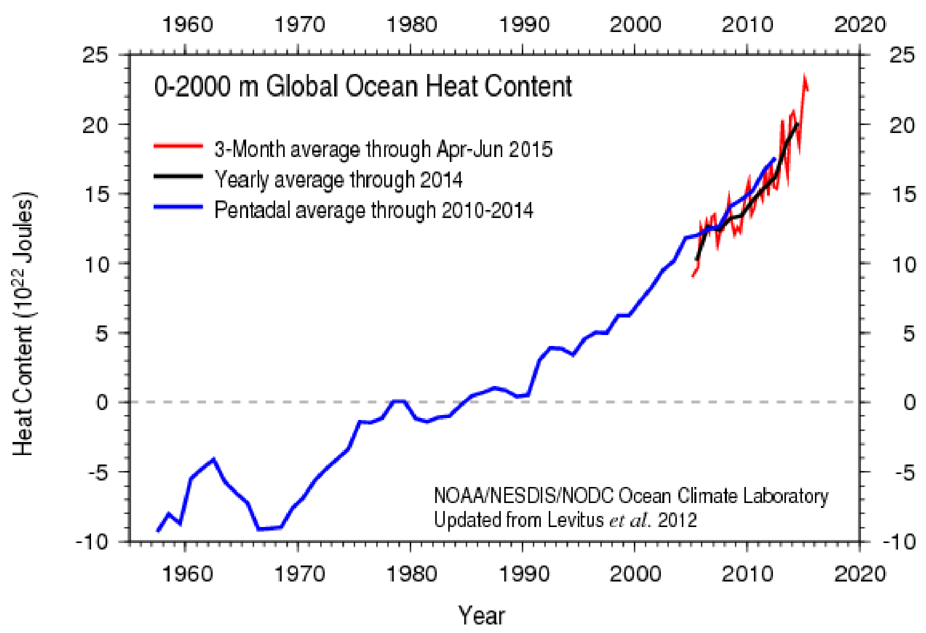


Figure 1.3-1

Then again, climate scientists have to manipulate the ocean heat content data in recent years to even show that warming. See Figure 1.3-2, which is the same as Figure Intro-13.

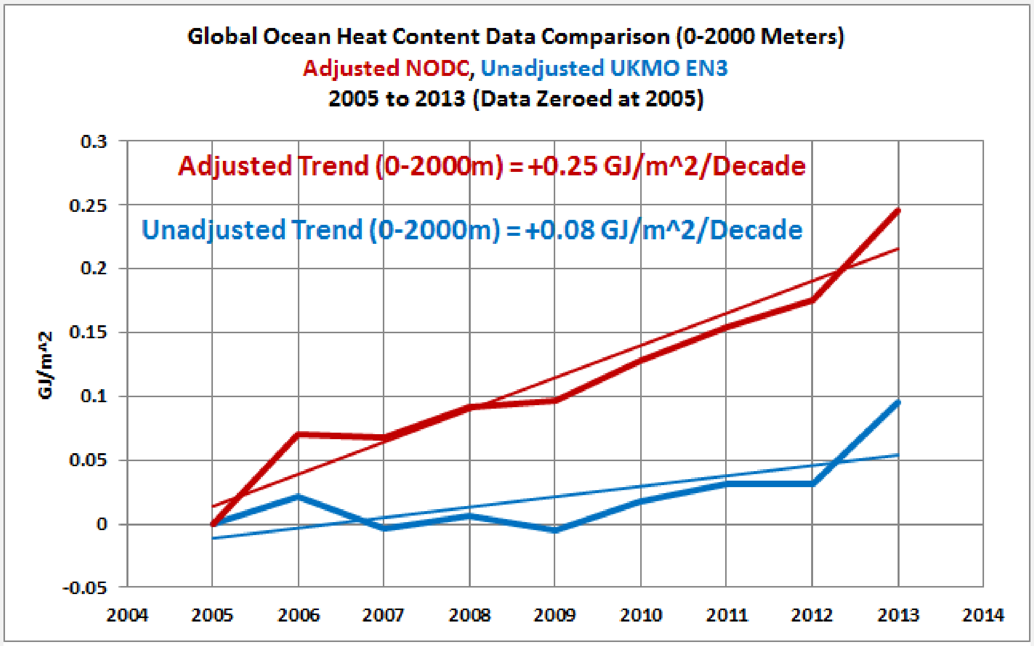


Figure 1.3-2

In reality, due to the massive heat capacity of oceans, the oceans warmed only a few one-hundredths of a deg C to depths of 2000 meters (about 6560 feet) during the surface warming slowdown…and that's after the adjustments to the ocean temperature measurements, without which the oceans would also show little to no warming to those depths.

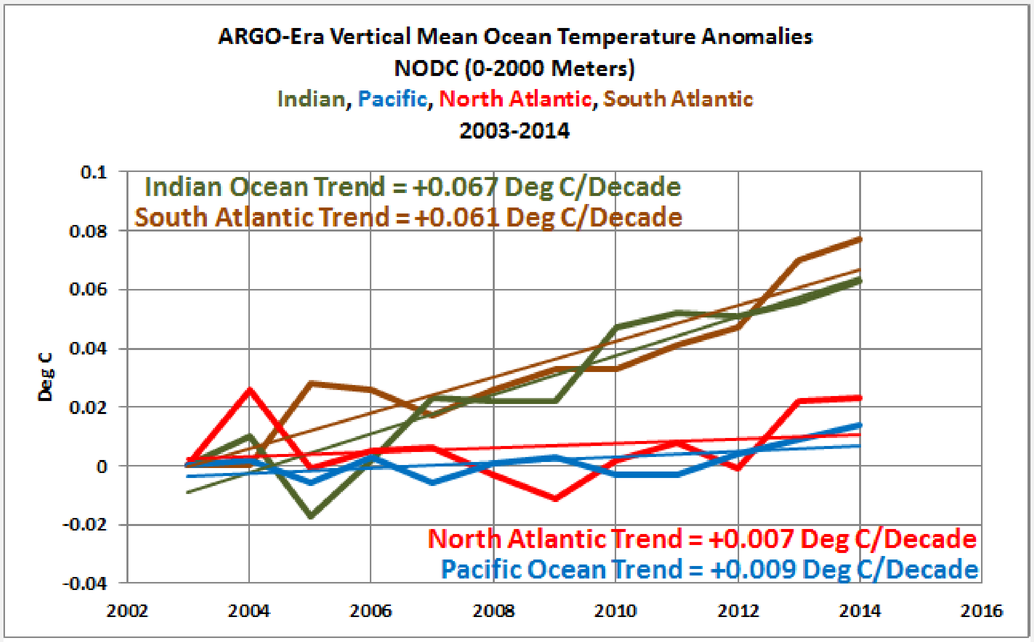


Figure 1.3-3

So there is no possible way that warming could come back to haunt us. That would defy the 2nd law of thermodynamics, which we'll discuss later in this section. (Don't worry; it's not hard to understand.) That additional warming of the deep oceans will simply add an ever-so-slight baseline to the surface warming when and if the surface warming continues at a higher rate.

How slight? As shown in Figure 1.3-3, it's measured in hundredths and thousandths of a deg C or deg F, depending on the ocean basin.

So while alarmists—or if you'd prefer: activists, partisans, campaigners or merchants—try to redirect the discussion from surface temperatures, to no avail, it is surface temperatures that are the primary metric of global warming. Does anyone other than climate scientists actually care if the oceans to depth warmed so many Joules times ten to the 22nd power? Most people don't know what a Joule is…and even fewer care.

Are politicians from around the globe meeting annually in order to draft a replacement treaty for the Kyoto Protocol designed to limit ocean warming to so many Joules? No. Are the treaties designed to limit increases in precipitation, hurricanes, droughts, etc.? No. Those treaties are efforts to limit an increase in global surface temperatures to 2.0

deg C above pre-industrial values…regardless of the fact that climate scientists are NOT sure what Earth’s surface temperature actually is.

Surface warming is still, by far, the primary metric of global warming.

1.4 – How Greenhouse Gases Warm the Surface of the Earth

First of all, the sun is the primary source of Earth's climate-related energy. Some of the sunlight is reflected back to space without reaching the surface…and some of the sunlight warms Earth's surface…and some of it penetrates into the oceans, warming the oceans below the surface.

Natural and man-made greenhouse gases in the atmosphere create an interesting effect. They allow sunlight to pass through the atmosphere and reach the surface of the planet. The Earth then radiates that heat back to outer space…or tries to radiate it back to space. And that's where greenhouse gases come into play. Greenhouse gases return some of the outgoing radiation back to the Earth's surface, causing it to be warmer than it would be if the greenhouse gases did not exist. That process is called the greenhouse effect. Figure 1.4-1 is a depiction of the greenhouse effect. That illustration is based on Figure 7 from Kiehl and Trenberth (1997) Earth's Annual Global Mean Energy Budget.

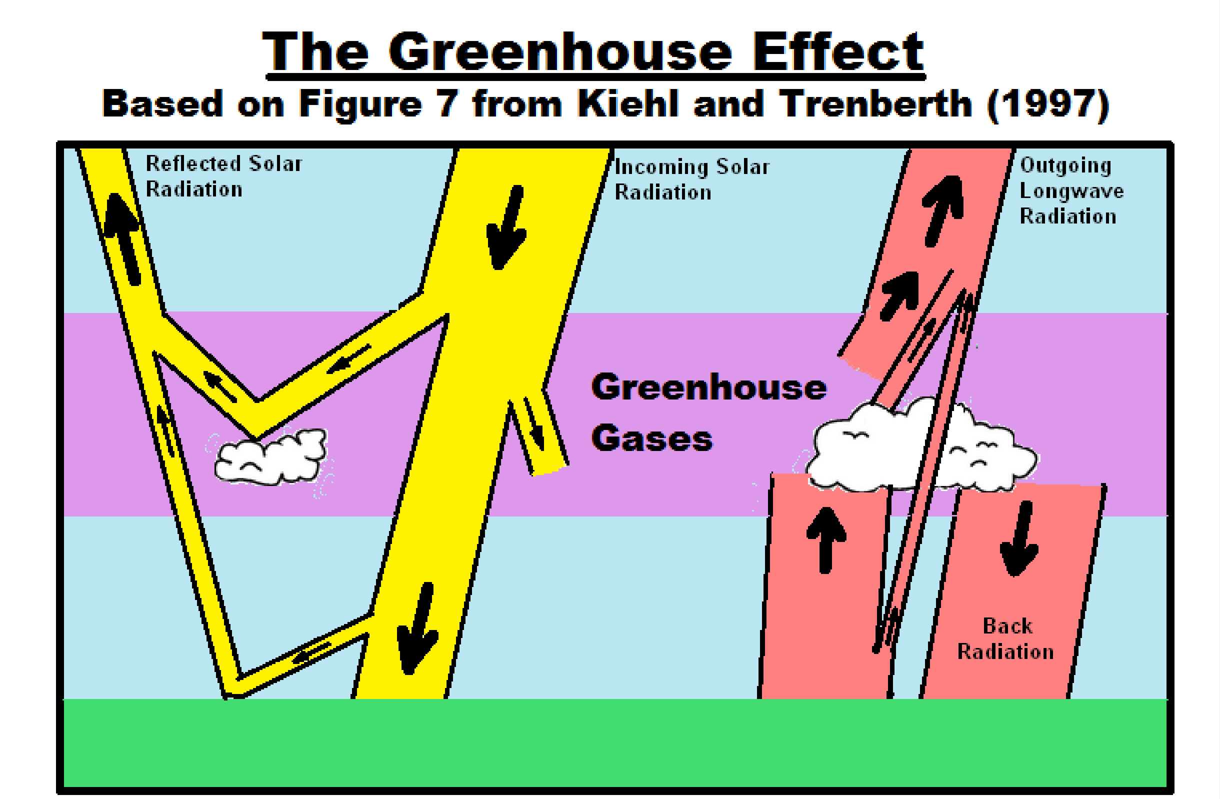


Figure 1.4-1

Man-made carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and fluorinated gases (chlorofluorocarbons) are listed by the U.S. EPA (Environmental Protection

Agency) as the four most-important man-made greenhouse gases. See the EPA webpage here.

Carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) also occur naturally. That is, those greenhouse gases have existed in the atmosphere long before humans added their contributions. And there is another naturally occurring greenhouse gas that is much more abundant than all of the other greenhouse gases combined. That greenhouse gas is water vapor. We'll discuss the role of water vapor in an upcoming chapter. But, bottom line, the naturally occurring greenhouse gases have warmed the Earth so that it is inhabitable.

-However-

The current groupthink is the additional greenhouse gases that mankind has added to the atmosphere are responsible for most of the global warming since the mid-1970s, and it is also believed that our continued emissions of man-made greenhouse gases will cause global surface temperatures to rise even more as we progress through the 21st Century. The Summary for Policymakers of the IPCC's (Intergovernmental Panel on Climate Change's) 5th Assessment Report includes (my boldface):

> *Human influence on the climate system is clear. This is evident from the increasing greenhouse gas concentrations in the atmosphere, positive radiative forcing, **observed warming**, and understanding of the climate system.*

Further, the beliefs that mankind is responsible for most of the warming since the mid-1970s are based on climate models…which are not simulating climate as it exists or has existed on Earth.

When people talk of the greenhouse effect or greenhouse gases, everyone assumes they're discussing the *enhanced* greenhouse effect caused by *man-made* greenhouse gases, not the naturally occurring greenhouse effect caused by naturally occurring greenhouse gases. Sometimes, though, that can lead to confusion. So be mindful of what's being discussed.

1.5 – What is Climate Change?

Climate change has two definitions, according to United Nation entities…not one, but two definitions. The IPCC Third Assessment Report defines climate change in their Appendix 1 - Glossary (My boldface.):

> *Climate change refers to a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer).* ***Climate change may be due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or in land use****.*

According to the IPCC, climate change can occur naturally or from man-made causes.

That IPCC definition, however, goes on to read:

> *Note that the →Framework Convention on Climate Change (UNFCCC), in its Article 1, defines "climate change" as: "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods". The UNFCCC thus makes a distinction between "climate change" attributable to human activities altering the atmospheric composition, and "climate variability" attributable to natural causes.*

The fact that there are two definitions is troubling because a person has to understand that there are multiple definitions of climate change when they are reading United Nations documents and their offspring.

It's also interesting that the UNFCCC (a United Nations policy) definition of climate change does not agree the IPCC (the United Nation's climate change report-writing entity) definition. To that end, we'll refer to a statement by Roger Pielke, Jr., from his book The Climate Fix: What Scientists and Politicians Won't Tell You About Global Warming. Roger Pielke, Jr., is a Professor in the Environmental Studies Program at the University of Colorado and a Fellow of the Cooperative Institute for Research in Environmental Sciences (CIRES). Pielke, Jr., writes:

> The IPCC adopts a broader definition of "climate change" that is more scientifically accurate. Claims that climate policy should be based on the work of the IPCC typically fail to recognize that the policy community has rejected the most fundamental statement of the IPCC on the issue – the very definition of "climate change".

See the Google Preview of *The Climate Fix* here.

That's an interesting realization, that the United Nations politicians don't accept the broader scientific definition of climate change. The politicians created their own term for natural climate change: "climate variability". It could be that the politicians wanted two separate terms to avoid confusion.

In the minds of most people, however, "climate change", like "global warming", has morphed into a term that implies man is responsible for the changes. In fact, the publication of the U.S. National Climate Assessment Report in May 2014 prompted Dr. Judith Curry (Professor and Chair of the School of Earth and Atmospheric Sciences at the Georgia Institute of Technology) to write at her blog ClimateEtc. (Her boldface.):

> *My main conclusion from reading the report is this:* ***the phrase 'climate change' is now officially meaningless.*** *The report effectively implies that there is no climate change other than what is caused by humans, and that extreme weather events are equivalent to climate change. Any increase in adverse impacts from extreme weather events or sea level rise is caused by humans. Possible scenarios of future climate change depend only on emissions scenarios that are translated into warming by climate models that produce far more warming than has recently been observed.*

And Dr. Curry began the closing of her post (My brackets.):

> *While there is some useful analysis in the report, it is hidden behind a false premise that any change in the 20th century has been caused by AGW [anthropogenic global warming].*

When we look at the commonly accepted definition of climate, we can understand the fallacy behind the premise that all changes in climate are now caused by mankind.

On their Frequently Asked Questions webpage, the World Meteorological Organization asks and answers:

> *What is Climate?*
>
> *Climate in a narrow sense is usually defined as the "average weather," or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical period is 30 years, as defined by the World Meteorological Organization (WMO). These quantities are most often surface variables such as temperature, precipitation, and wind. Climate in a wider sense is the state, including a statistical description, of the climate system.*

“Average weather” is a wonderful definition of climate. We know that weather is chaotic and that weather is always changing and has always changed…and will continue to change in the future. Therefore, climate is always changing and has always changed…and will continue to change in the future.

By blaming all changes in weather on mankind, reports like the *U.S. National Climate Assessment Report* imply that extreme weather can be minimized by eliminating our emissions of man-made greenhouse gases—providing a false hope to naïve persons of a future without hurricanes and tropical cyclones, without tornados, without blizzards, without droughts, without floods. They further suggest to those trusting souls that all we have to do to make weather nonthreatening on our planet is drive efficient cars, install solar panels on our roofs and install wind farms everywhere. That suggestion is not only misleading, it’s foolish. Weather has always changed, and it will continue to change in the future. Because climate is average weather, climate has always and will always change.

Further, climate scientists must rely on computer models to predict how climate and weather might change in the future in response to the increased emissions of man-made greenhouse gases. And that raises the question: Are climate models capable of simulating the factors that are of interest to people and policymakers? The realistic answer is no…as you have already seen and will continue to see throughout this book. Climate models will be of value only after they are capable of simulating the natural factors that can contribute to or suppress man-made global warming and that cause climate to change. And climate modelers are nowhere close to being able to simulate those factors.

Like greenhouse gases and global warming, when the term climate change is used, everyone now assumes the human-induced variety is being discussed…when, in fact, the speaker or author might be referring to naturally caused variations in climate. This problem was recently presented in the testimony of Dr. Daniel B. Botkin (Professor Emeritus from the University of California Santa Barbara) at a hearing for the U.S. House of Representatives Committee on Science, Space and Technology (May 29, 2014). The subject of the hearing was Examining the UN Intergovernmental Panel on Climate Change Process. If you were to read Dr. Botkin’s environmental background (See his webpage here.), you’d be convinced his testimony would be full of praise for the IPCC. Surprisingly, that was not the case. See his written statement here. About the use of the term climate change in the recent IPCC report, Dr. Botkin wrote:

> *The reports suffers [sic] from the use term “climate change” with two meanings: natural and human-induced. These are both given as definitions in the IPCC report and are not distinguished in the text and therefore confuse a reader. (The Climate Change Assessment uses the term throughout including its title, but*

never defines it.) There are places in the reports where only the second meaning—human induced—makes sense, so that meaning has to be assumed. There are other places where either meaning could be applied.

In those places where either meaning can be interpreted, if the statement is assumed to be a natural change, then it is a truism, a basic characteristic of Earth's environment and something people have always know and experienced. If the meaning is taken to be human-caused, then in spite of the assertions in the report, the available data do not support the statements.

Dr. Botkin's statement is chock full of similar realities about the IPCC reports. Please take the time to read it. Another link to his written statement is here.

Screen Capture Of NOAA/CPC "Climate Variability" Webpage

http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensocycle/clim_vari.shtm

Figure 1.5-1

Figure 1.5-1 is a screen capture of the four photos at the top of the NOAA **Climate variability** webpage. (Archived here.) They show a thunderstorm, strong waves eroding a beach, a wildfire, and a pickup truck on a highway partly submerged by a flood.

But is NOAA presenting those illustrations in a discussion of naturally caused or anthropogenically caused weather events?

In recent years, we've seen similar photographs used repeatedly by climate change alarmists as misleading "proof" of anthropogenic climate change, yet the images in Figure 1.5-1 weren't used in a discussion of man-made global warming. They were included in a discussion of weather, specifically El Niño-Southern Oscillation (a.k.a. ENSO, El Niño and La Niña events), the largest weather events on Earth. NOAA/CPC provides an excellent overview of natural climate variability/change on that webpage. The text on that NOAA webpage reads (my boldface):

> *One of the most prominent aspects of our weather and climate is its variability. This variability ranges over many time and space scales, from small-scale phenomena such as wind gusts, localized thunderstorms and tornadoes, to larger-scale features such as fronts and storms, to even more prolonged features such as droughts and floods, and to fluctuations occurring on multi-seasonal, multi-year, multi-decade and even multi-century time scales. Some examples of these longer time-scale fluctuations include an abnormally hot and dry summer, an abnormally cold and snowy winter, a consecutive series of abnormally mild or exceptionally severe winters, and even a mild winter followed by a severe winter. In general, the longer time-scale phenomena are often associated with changes in the atmospheric circulation that encompass areas far larger than a particular affected region. At times, these persistent circulation features occur simultaneously over vast, and seemingly unrelated, parts of the hemisphere, or even the globe, and result in abnormal weather, temperature and rainfall patterns throughout the world.* ***During the past several decades, scientists have discovered that important aspects of this interannual variability in global weather patterns are linked to a global-scale, naturally occurring phenomenon known as the El Niño/ Southern Oscillation (ENSO) cycle. The terms El Niño and La Niña represent opposite extremes of the ENSO cycle****.*

Once again, be careful when you read the phrase climate change, or see photos of weather events. Are the authors discussing naturally caused weather or climate change or anthropogenically caused?

CHAPTER CLOSING

Were you aware that the IPCC and other government agencies used *climate change* for both natural and human-induced variability…often without identifying which they're discussing? Did you assume they were discussing the man-made type, when in fact they may have been referring to natural variability?

Some persons might believe the IPCC and other governmental agencies are purposely being vague, with hope that most readers will assume they're discussing the man-made kind, when in reality those scientists still can't differentiate between natural and anthropogenic climate change.

1.6 – Is There Any Way to Prove Man is Responsible for Most of the Global Warming in Recent Decades?

Quick answer: No.

The following, or something similar, has been said many times before: there are no planets exactly like Earth that scientists can use for experiments, and, the experiments would require centuries to run, so they wouldn't be practical if those other planets existed. As a result, scientists must rely on climate models to determine how much of the warming since the mid-1970s was caused by the emissions of man-made greenhouse gases and how much more global surface temperatures might warm and how climate might change if we continue to emit greenhouse gases into the atmosphere.

WHAT HAVE CLIMATE SCIENTISTS PROVEN WITH CLIMATE MODELS?

The climate science community has only proven that they can write computer programs so that, in the imperfect virtual representations of our Earth within those models, they can cause the modeled Earth to warm by adding numerical representations of greenhouse gases to the calculations used to simulate Earth's oceans, land surfaces and atmosphere.

But that does not prove man-made greenhouse gases in the real world were responsible for the changes in global temperatures and climate—especially when the models are still not able to simulating naturally occurring, sunlight-fueled processes like those associated with El Niño events.

Maybe it's easier to think of climate models along the lines of something we've become accustomed to seeing on a daily basis: the virtual reality of computer-generated imagery. Was Godzilla real in any of its recent reincarnations? No. Godzilla is a fantasy creature, demolishing a virtual world. Those were computer-generated images. Likewise, the numerical representations of oceans and atmospheres in climate models are not real. They are computer-generated virtual worlds. Unfortunately, there is nothing magical about climate models…other than the over-marketing of their capabilities.

Basically, the only thing that the climate models have proven is that man-made greenhouse gases **could have** caused the warming and changes in climate we've experienced in recent decades…not that they have. People have lost sight of that simple reality. Climate models only indicate that global warming and climate change **could have** been caused the increased emissions of greenhouse gases.

Unfortunately, climate modelers are no closer now than they were in the 1990s to being able to actually attribute global warming and climate change to man-made greenhouse gases, because the climate models still cannot simulate naturally occurring ocean-atmosphere processes that contribute to or suppress variations in surface temperatures and climate.

1.7 – A Very Brief Introduction to Climate Feedbacks

"Climate feedbacks" are processes that enhance (positive feedback) or suppress (negative feedback) a change in climate. See Figure 1.7-1 for simple flowcharts of positive and negative feedbacks.

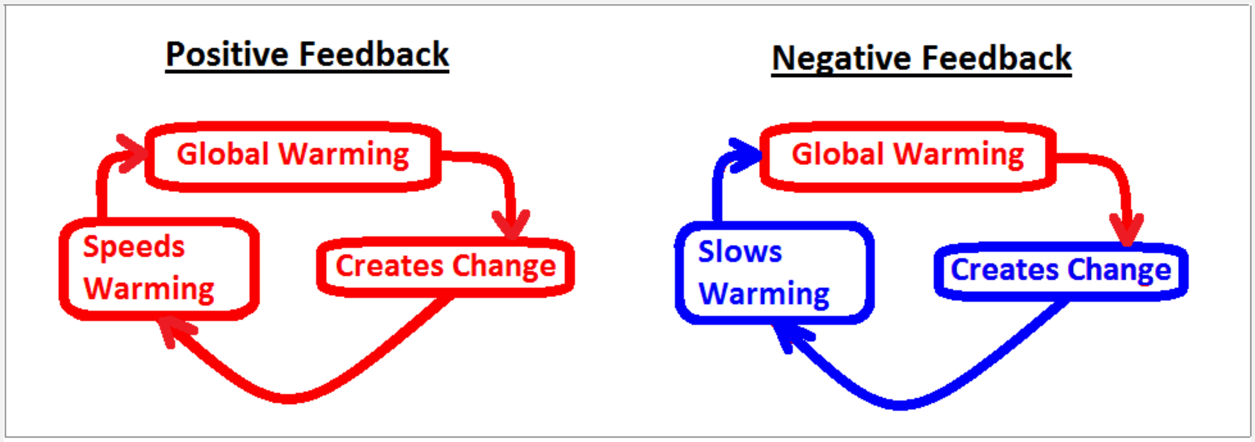


Figure 1.7-1

Phrased differently, positive feedbacks amplify the effects of a change in climate and negative feedbacks diminish their effects.

Very good examples of positive and negative feedbacks are discussed in the next chapter.

1.8 – Water Vapor: The Most Abundant Greenhouse Gas

Water vapor was mentioned earlier. It was noted that water vapor is the most abundant greenhouse gas. Just how dominant is it? Figure 1.8-1 shows the contributions (as a percentage) of greenhouse gases to the greenhouse effect. **Please note that these include both natural and man-made contributions**. They were presented in Kiehl and Trenberth (1997) Earth's Annual Global Mean Energy Budget. See their Table 3. Water vapor is estimated to contribute about 60% of the greenhouse effect, while the closest other contributor is CO_2 from man-made and natural sources, which account for less than half of the water vapor contribution (26%).

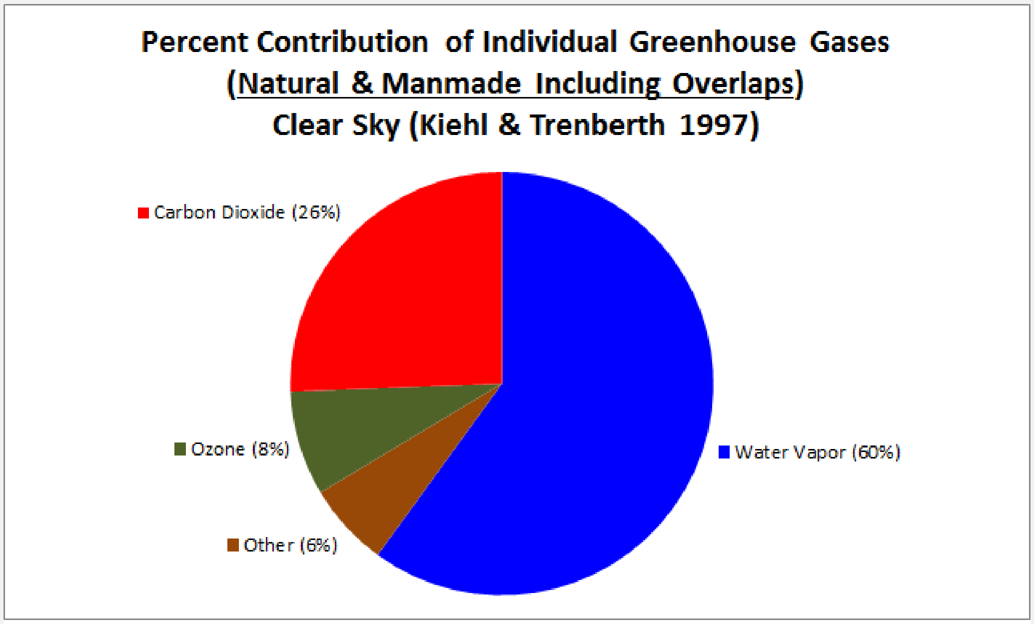


Figure 1.8-1

The above pie chart is for clear sky conditions. The percentages change a few points for cloudy skies, with water vapor dropping to 59%, based on Kiehl and Trenberth (1997).

Note: Again, that pie chart includes the contribution of both natural and man-made greenhouse gases. In Chapter 1.10, there's a more-revealing pie chart (Figure 1.10-2) that shows how small the contribution of man-made greenhouse gases is to Earth's radiative imbalance. [End note.]

NOAA's (National Oceanic and Atmospheric Administration) NCDC (National Climatic Data Center) Greenhouse Gases website (archived copy) includes discussions of greenhouse gases. The Water Vapor webpage linked there begins (my boldface):

> *Water Vapor is the most abundant greenhouse gas in the atmosphere, which is why it is addressed here first. However, changes in its concentration is [sic] also considered to be a result of climate* feedbacks *related to the warming of the atmosphere rather than a direct result of industrialization.* ***The feedback loop in which water is involved is critically important to projecting future climate change, but as yet is still fairly poorly measured and understood****.*

The word *assumed* would probably be more realistic than *considered* in the second sentence, especially when we consider that "as yet [the water vapor feedback loop] is still fairly poorly measured and understood."

Phrased another way, NOAA acknowledges that water vapor is the most plentiful greenhouse gas in the atmosphere, and they assume that water vapor has changed due to the warming of the atmosphere. They state that water vapor is very important. NOAA also notes that they are not able to measure it well and that they do not understand how water vapor has changed in the past and will change in the future.

NOAA continues their discussion of feedbacks (my boldface):

> *As the temperature of the atmosphere rises, more water is evaporated from ground storage (rivers, oceans, reservoirs, soil). Because the air is warmer, the absolute humidity can be higher (in essence, the air is able to 'hold' more water when it's warmer), leading to more water* vapor *in the atmosphere. As a greenhouse gas, the higher concentration of water vapor is then able to absorb more thermal IR energy radiated from the Earth, thus further warming the atmosphere. The warmer atmosphere can then hold more water vapor and so on and so on. This is referred to as a 'positive feedback loop'.* ***However, huge scientific uncertainty exists in defining the extent and importance of this feedback loop****. As water vapor increases in the atmosphere, more of it will eventually also condense into clouds, which are more able to reflect incoming solar radiation (thus allowing less energy to reach the Earth's surface and heat it up). The future monitoring of atmospheric processes involving water vapor will be critical to fully understand the feedbacks in the climate system leading to global climate change.* ***As yet, though the basics of the hydrological cycle are fairly well understood, we have very little comprehension of the complexity of the feedback loops.*** *Also, while we have good atmospheric measurements of other key greenhouse gases such as carbon dioxide and methane, we have poor measurements of global water vapor, so it is not certain by how much atmospheric concentrations have risen in recent decades or centuries, though satellite measurements, combined with balloon data and some in-situ ground measurements indicate generally positive trends in global water vapor.*

In other words, as the atmosphere warms, more water from the surface of the oceans, seas, lakes and soil evaporate into the atmosphere. And because the atmosphere is warmer, it can hold more water vapor, which, because it is a greenhouse gas, would lead to more warming and more evaporation. The warming atmosphere and the increases in evaporation and water vapor reinforce one another, meaning that, if there was nothing else to counteract it, the warming atmosphere would lead to more evaporation and then more water vapor in the atmosphere, which would lead to more warming because water vapor is a greenhouse gas, and so on, in a never-ending warming loop with "positive feedback".

-However-

Clouds counteract that positive feedback. When the water evaporates from the surface, much of it is carried high into the atmosphere. The atmosphere is cooler at higher altitudes, so as that moisture rises, it cools, and as it cools, it condenses and forms clouds. The clouds then block sunlight, which provides a negative feedback and limits the warming. That is, more water vapor causes more clouds, which limits the amount of sunlight that can reach the surface of the Earth…and that has a cooling effect. So there is, and has always been, a balancing act taking place between the greenhouse gases and clouds.

One of the big uncertainties with the hypothesis of human-induced global warming arises from clouds. As NOAA states above (my boldface):

> *However, huge scientific uncertainty exists in defining the extent and importance of this feedback loop… As yet, though the basics of the hydrological cycle are fairly well understood,* ***we have very little comprehension of the complexity of the feedback loops****.*

That is, climate scientists do not know for sure the extent to which clouds will limit the impacts of man-made greenhouse gases. Climate scientists have to assume the overall feedback will be positive, because they need the positive feedback, in response to the increased emissions of greenhouse gases, in order to reproduce, in climate models, the warming that had taken place from the mid-1970s to about 2000. If the clouds in the real world counteract all of the warming taking place because of the increased water vapor, then the overall feedback is neither positive nor negative—and global surfaces will warm less than projected by the climate models. Then again, if the increase in clouds creates more cooling than water vapor creates heating, then the overall feedback would be negative, so global surface temperatures could warm even less in response to increased emissions of greenhouse gases. A negative feedback would also suggest the warming we've seen in recent decades was natural.

Let's clarify something. In theory, the doubling of man-made greenhouse gases from preindustrial levels will only cause surface temperatures to rise about 1 deg C (1.8 deg F). In order for climate models to produce the enhanced warming on the orders of 2 deg C to 4 deg C (3.6 deg F to 7.2 deg F) for a doubling of CO2, they require positive feedback, primarily from water vapor. But the climate science community does not know if those feedbacks are in fact positive. They will argue until they're blue in the face that the feedbacks are positive, because they use positive feedbacks to create the additional warming, but one of the greatest uncertainties in climate science is the sign and strength of water vapor feedback.

Curiously, as we discussed and illustrated in the Introduction, climate models show no increase in global precipitation from 1861 (the start year for many of the models) through to 1999, based on the linear trend. We showed that in Figure Intro-15, which I've included below again as Figure 1.8-2.

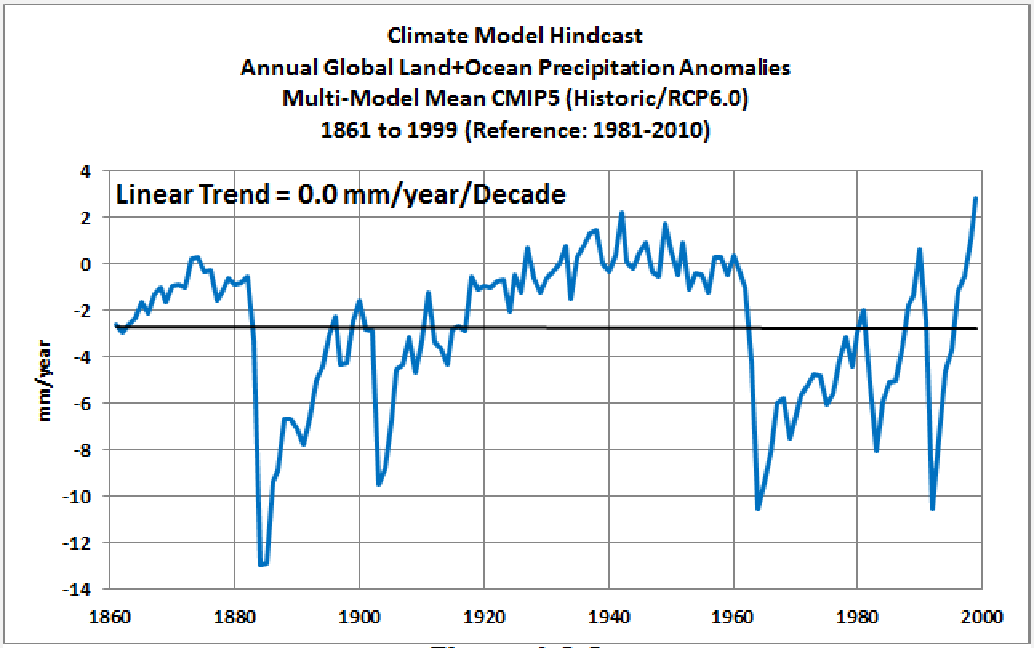


Figure 1.8-2

Surface temperature data indicate the Earth's surfaces have warmed over that time period, precipitation data for land surfaces also show an increase, so we would have expected modeled water vapor and precipitation to have increased, too. Yet the climate models used by the IPCC for their 5th Assessment Report show no long-term increase in global precipitation from 1861-1999.

1.9 – The Global Energy Budget

The Earth is often described as an energy system with incoming and outgoing sources of energy. It is further said to have a budget—commonly referred to as the “global energy budget” or “Earth’s energy budget”. The incoming energy source is sunlight, of course, and the outgoing energy is infrared (longwave) radiation. There are many climate-related factors that influence or interact with those incoming and outgoing sources of energy. My Figure 1.9-1 is a facsimile of Figure 7 from Kiehl and Trenberth (1997) Earth’s Annual Global Mean Energy Budget. In their 4th Assessment Report, the IPCC used the Kiehl and Trenberth (1997) illustration for their FAQ1.1, Figure 1. The IPCC has a reasonably easy-to-understand discussion of that illustration in their FAQ 1.1 What Factors Determine Earth’s Climate? webpage.

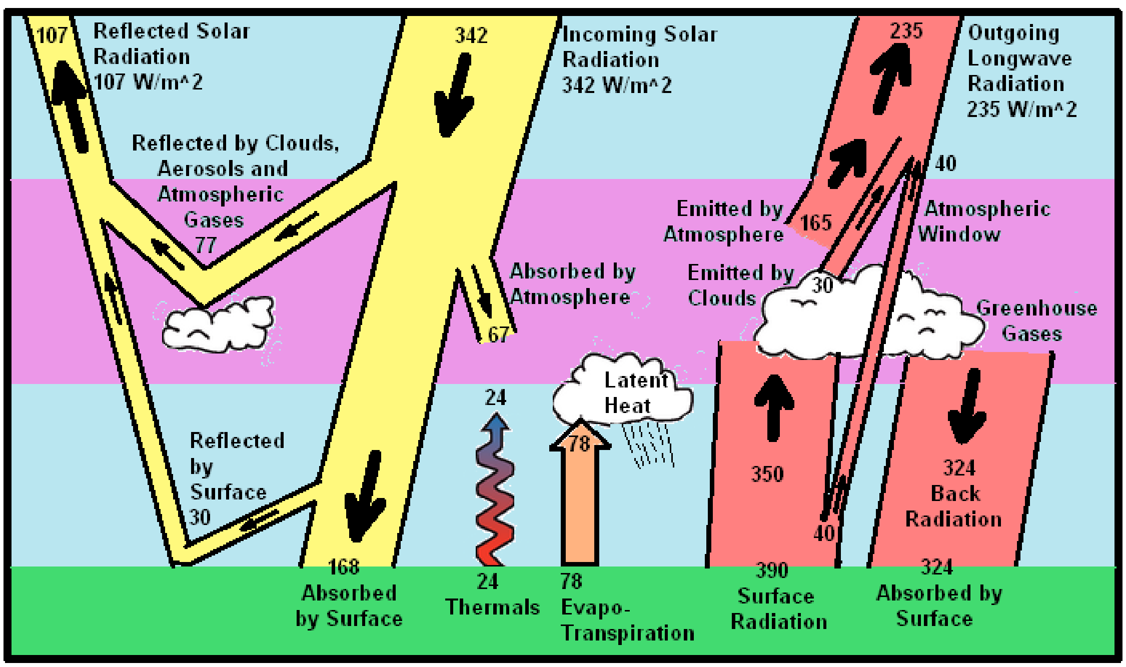


Figure 1.9-1

The values for many of the metrics are estimates. Solar energy at the top of the atmosphere is measured with satellites, of course, and it varies a little on decadal timescales. Cloud cover also varies in response to weather and in response to other factors that are still unknown. As a result, the other values also change with time.

Notice the primary values listed across the top; they balance in this example. That is, the Incoming Solar Radiation value of 342 watts/m^2 equals the sum of the Reflected

Solar Radiation (107 watts/m^2) plus the Outgoing Longwave (Infrared) Radiation (235 watts/m^2). That means the global energy budget balances in that illustration.

And that’s a logical lead-in to a discussion of energy imbalance in the next chapter.

1.10 – Introduction to Radiative Imbalance

Climate scientists have estimated that the global energy budget is out of balance due to the increased emissions of man-made greenhouse gases, and they refer to this state as the "radiative imbalance." Basically, according to the climate scientists, anthropogenic greenhouse gases are preventing the Earth from radiating energy back into space at the same rate as the solar energy being radiated to it.

Satellites had already been in place since the late 1970s to measure the incoming solar radiation at the top of the atmosphere. To track the actual radiative imbalance, satellites have been used since 1997 to monitor outgoing solar and infrared radiation. They are part of NASA's Clouds and Earth's Radiant Energy System (CERES). But climate scientists ran into a problem. The measured radiative imbalance was way too large. It turns out that the satellites have great resolution—they measure minute changes in radiation—but they're not very accurate. That is, it's like being able to monitor how much a bank account balance varies to the penny, while not knowing if the account holds $10,000.00 or $15,000.00.

The 2011 paper The Earth's Energy Imbalance and Implications by Hansen et al. includes a brief but easy-to-understand explanation of the problem and how they initially worked around it:

> *The precision achieved by the most advanced generation of radiation budget satellites is indicated by the planetary energy imbalance measured by the ongoing CERES (Clouds and the Earth's Radiant Energy System) instrument (Loeb et al., 2009), which finds a measured 5-yr-mean imbalance of 6.5Wm*$^{-2}$ *(Loeb et al., 2009). Because this result is implausible, instrumentation calibration factors were introduced to reduce the imbalance to the imbalance suggested by climate models, 0.85Wm*$^{-2}$ *(Loeb et al., 2009).*

Phrased differently, because the satellites were inaccurate, climate scientists had to rely on the outputs of climate models and assume they were correct. And that's a great big assumption.

The atmosphere does not hold much heat, but the oceans do, so there is another way to estimate the imbalance: determine the rate at which the oceans are storing heat. This presented the climate scientists with another problem. They could use subsurface ocean temperatures (and salinity, since the saltiness of the oceans also impacts the amount of heat the oceans can hold), but there were very few measurements of temperature and salinity before the early 2000s. That's when an international program called ARGO began deploying a series of floats (that automatically submerse and surface, spending most of their time below the surface) to monitor the temperature and salinity of the top 2000 meters (roughly 6600 feet) of the global oceans.

We'll discuss and illustrate the problems with the ocean heat content data in the upcoming Part 2 and confirm that the estimate of ocean heat uptake was questionable before the ARGO floats were deployed. (Also see the post Is Ocean Heat Content Data All It's Stacked Up to Be?)

Then the climate science community ran into yet another problem after they had a few years of the ARGO-based ocean heat content data: the oceans were shown to be cooling, not warming. Those findings were presented in the Lyman et al. (2007) paper Recent cooling of the upper ocean. Needless to say, that news was not well received by the climate science community.

Using satellite-based sea level data, specialists concluded that there were problems with some of the ARGO floats, and once the data from the bad floats were removed, the oceans were shown to have warmed…but the observed warming was still less than predicted by the models…and that problem still exists.

Back to radiative imbalance:

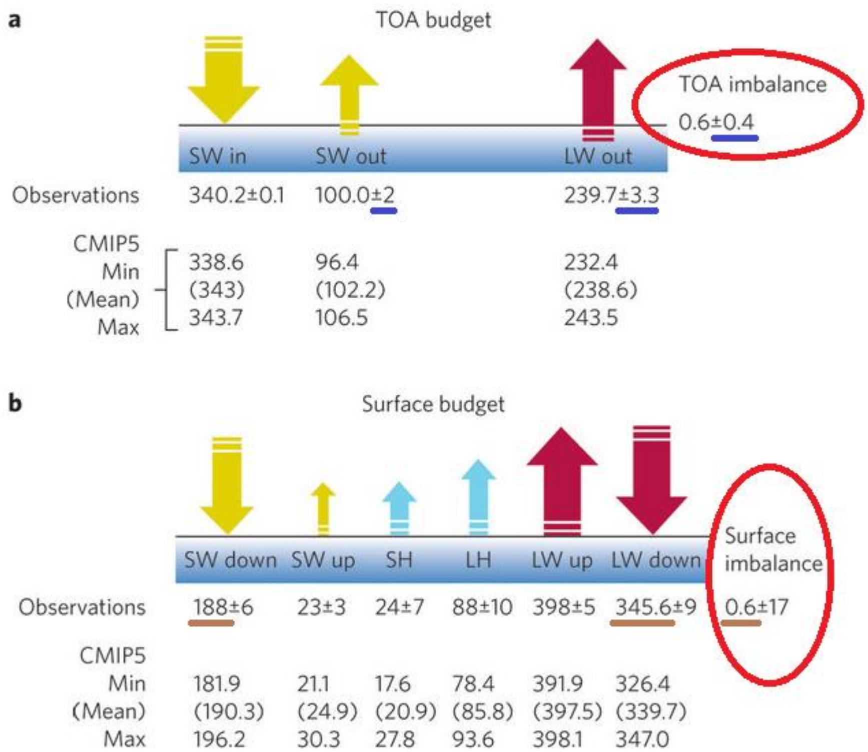
Climate scientists have re-estimated the global energy imbalance using the satellite observations of incoming and outgoing radiation and the ocean heat content data from the corrected (adjusted) ARGO floats. A recent example is the Stephens et al, (2013) paper An update on Earth's energy balance in light of the latest global observations. A preprint edition is here. Also see the Supplementary Information here. My Figure 1.10-1 is an annotated version of Figure 1 from Stephens et al, (2013).

The Stephens et al, (2013) caption for their Figure 1 reads:

> ***Figure 1 | Surface energy balance.*** *Observed and climate model deduced energy fluxes (all in Wm^{-2}) in and out of the TOA (**a**) and at the surface (**b**). The observed fluxes (containing error estimates) are taken from Fig. B1 and the climate model fluxes are from simulations archived under the World Climate Research Programme's Coupled Model Intercomparison Project phase 5 (CMIP5) twentieth-century experiments. The fluxes from a 16-model ensemble are summarized in terms of the range in model values (maximum and minimum fluxes) with the ensemble mean fluxes given in parenthesis. 'SW in' and 'SW out' refer to the incoming and outgoing (reflected) solar fluxes at the TOA and 'LW out' is the outgoing longwave radiation. Similarly 'SW down' and 'SW up' refer to downward and upward (reflected) solar fluxes at the surface, and 'LW up' and 'LW down' refer to the upward emitted flux of longwave radiation from the surface*

and the downward longwave flux emitted from the atmosphere to the surface, respectively. SH and LH refer to latent and sensible heat fluxes.

Figure 1 from Stephens et al (2013) "An Update on Earth's Energy Balance in Light of the Latest Global Observations"



Source: http://www.nature.com/ngeo/journal/v5/n10/images_article/ngeo1580-f1.jpg

Figure 1.10-1

There are a number of things to note in the above illustration. First, underlined in blue, at top of the atmosphere, the uncertainties of the individual measurements of outgoing shortwave radiation (reflected sunlight) and outgoing longwave (infrared) radiation are much greater than the uncertainty of the imbalance. The reasons for this are (1) the uncertainties listed for the individual components are based on the satellites, while (2) the imbalance is based on the ARGO data (which have to be adjusted to show warming. I mentioned that above and we'll discuss it more later in Part 2 of this book). Second, circled in red in cell b, the surface imbalance is estimated to be 0.6 +/- 17 watts/m^2. That is, the uncertainties of +/- 17 watts/m^2 are much greater than the imbalance, or phrased another way, based on surface measurements, we really do not know the actual energy imbalance. Third, underlined in brown, note how the energy imbalance at the surface is an extremely small portion of the total of the downward shortwave radiation (sunlight) and downward longwave radiation (natural and man-made) at the surface. That is, the surface imbalance is only 0.6 watts/m^2, while the sum of the downward shortwave and downward longwave radiation is about 533 watts/m^2…or the surface imbalance is only 0.11% (about one-tenth of one percent) of the sum of the downward shortwave and downward longwave radiation. The imbalance is miniscule compared to the downward radiation the Earth sees every day. To give you an idea of just how small the surface imbalance is compared to the downward shortwave (sunlight) and longwave (infrared) radiation at the surface, see the pie chart in Figure 1.10-2. The teeny little black line, which is difficult to see, represents the radiative imbalance.

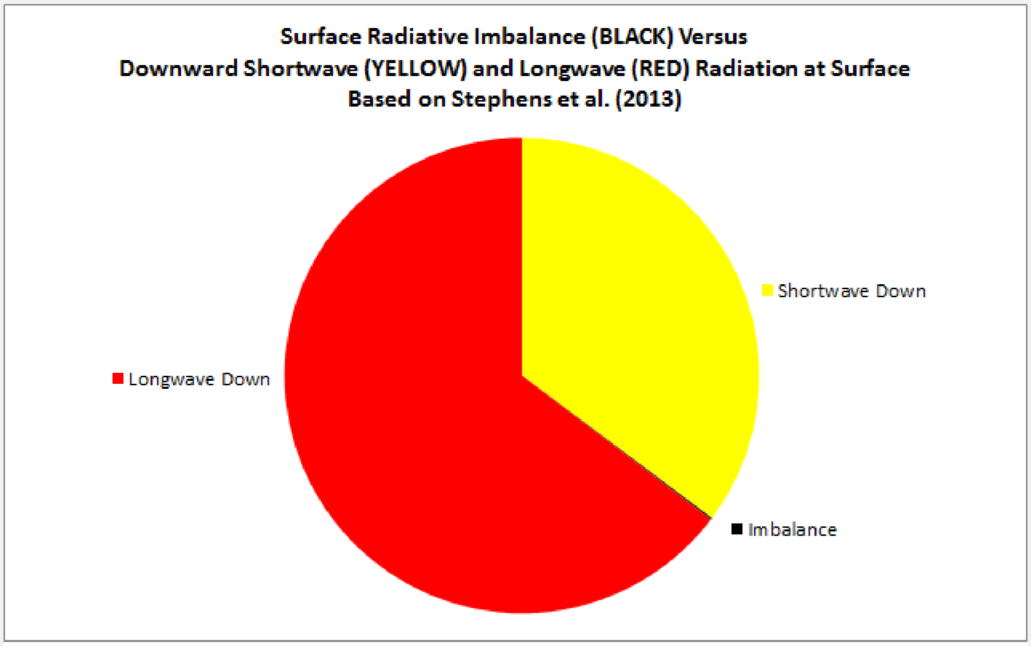


Figure 1.10-2

CLOSING FOR THE GENERAL DISCUSSION PORTION OF THIS CHAPTER

Bottom line, the emissions of man-made greenhouse gases have created an energy imbalance so small that it cannot be measured directly. The imbalance has to be implied from the increase in ocean heat content data, but the ocean heat content data have to be adjusted to show that warming. The climate science community also assumes that all of the increase in ocean heat content from their much-adjusted data was caused by anthropogenic greenhouse gases, while the data suggests that natural factors were the primary cause. We'll discuss these other possible reasons for the radiative imbalance in future chapters.

THERE IS NO CONSENSUS IN THE CLIMATE MODEL SIMULATIONS OF THE ENERGY IMBALANCE AT THE TOP OF THE ATMOSPHERE

I was curious about how well climate models simulate the energy imbalance at the top of the atmosphere. Knowing how poorly climate models simulate global surface temperatures, precipitation and sea ice, I was not surprised by my findings for the energy imbalance. See the post No Consensus: Earth's Top of Atmosphere Energy Imbalance in CMIP5-Archived (IPCC AR5) Climate Models for the details. The following is a summary.

Figure 1.10-3 presents the model hindcasts (up to 2005) and forecasts (starting in 2006) of the top of the atmosphere energy imbalance from 21 climate models stored in the CMIP5 archive, using the historic and RCP6.0 forcings.

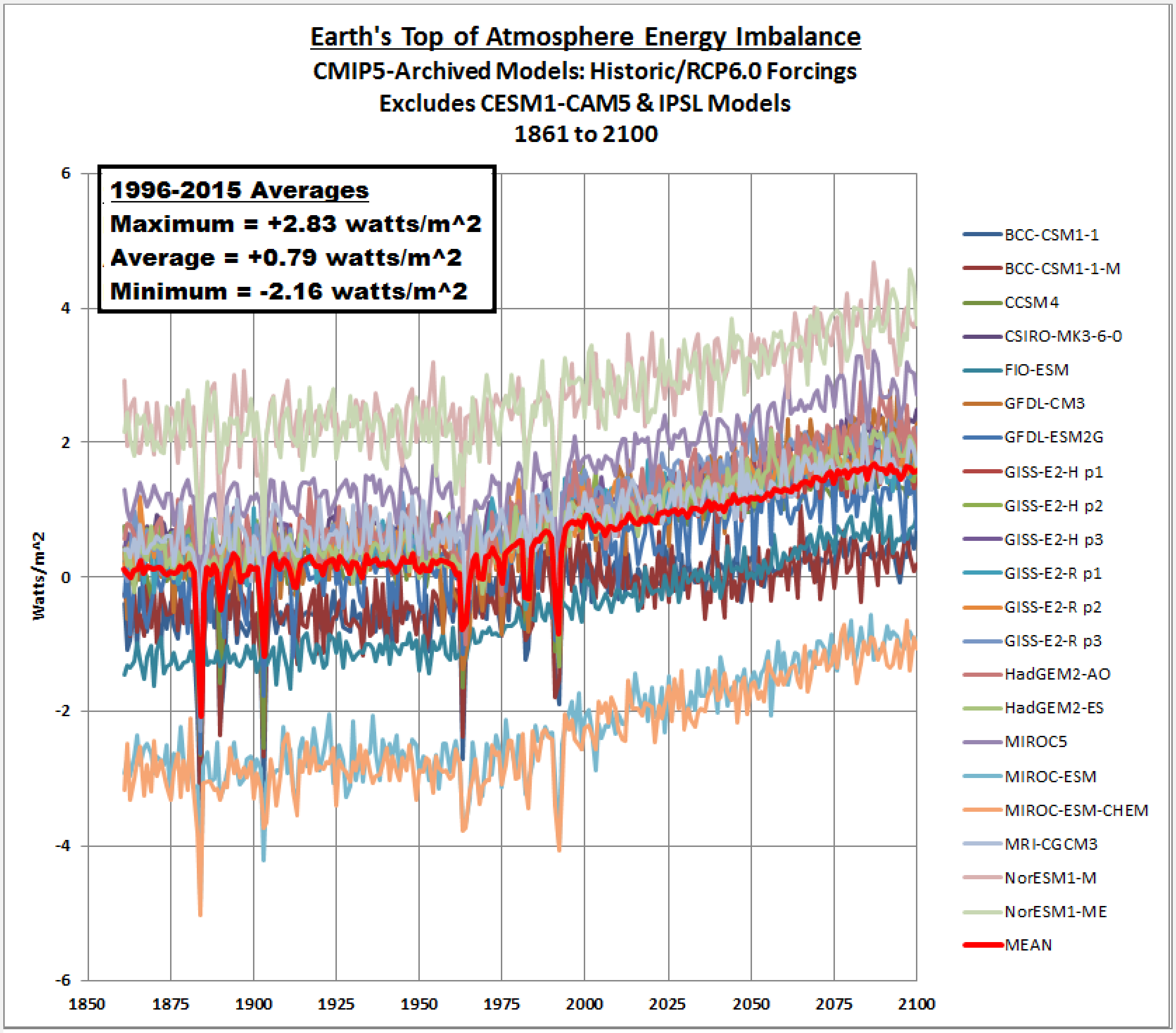


Figure 1.10-3

The +0.79 watts/m^2 average (the model mean) for the period of 1996 to 2015 is about what we would expect. But the modeled values span more than 5 watts/m^2 during that period.

Recall that Hansen et al. (2012) said that a 6.5 watts/m^2 energy imbalance was considered “implausible”. What about model-simulated energy imbalances of -2.2 watts/m^2 and +2.8 watts/m^2? Are those values implausible as well? If so, why are those models used by the IPCC?

Trenberth et al. (2014) Earth’s Energy Imbalance gave us an approximate range for the energy imbalance of 0.5 to 1.0 watts/m^2. There are 5 models that produce an energy imbalance greater than 1.2 watts/m^2 for the base period of 1996-2015. If they’re right, then there’s even more heat than is presently unaccounted for by the ocean heat content data. They’ll have to call out more search parties to look for all of that missing heat.

Then there are the four models that show a negative imbalance during our base period of 1996-2015. If those models are correct, then the hypothesis of human-induced global warming has a very big problem. A negative imbalance indicates that presently more energy is being reflected and emitted by the planet than is being received from the sun…and that our emissions of greenhouse gases are returning the Earth to a balanced energy budget.

Figures 1.10-4 through 1.10-6 present the model simulations of the three components that make up the energy imbalance at the top of the atmosphere:

- Figure 1.10-4 is the TOA Incident Shortwave Radiation (incoming downward solar radiation). It is basically an input to the models.
- Figure 1.10-5 is the TOA Outgoing Shortwave Radiation (reflected solar radiation). It is a computer-calculated value.
- Figure 1.10-6 is the TOA Outgoing Longwave Radiation (emitted infrared radiation). It is also a computer-calculated value.

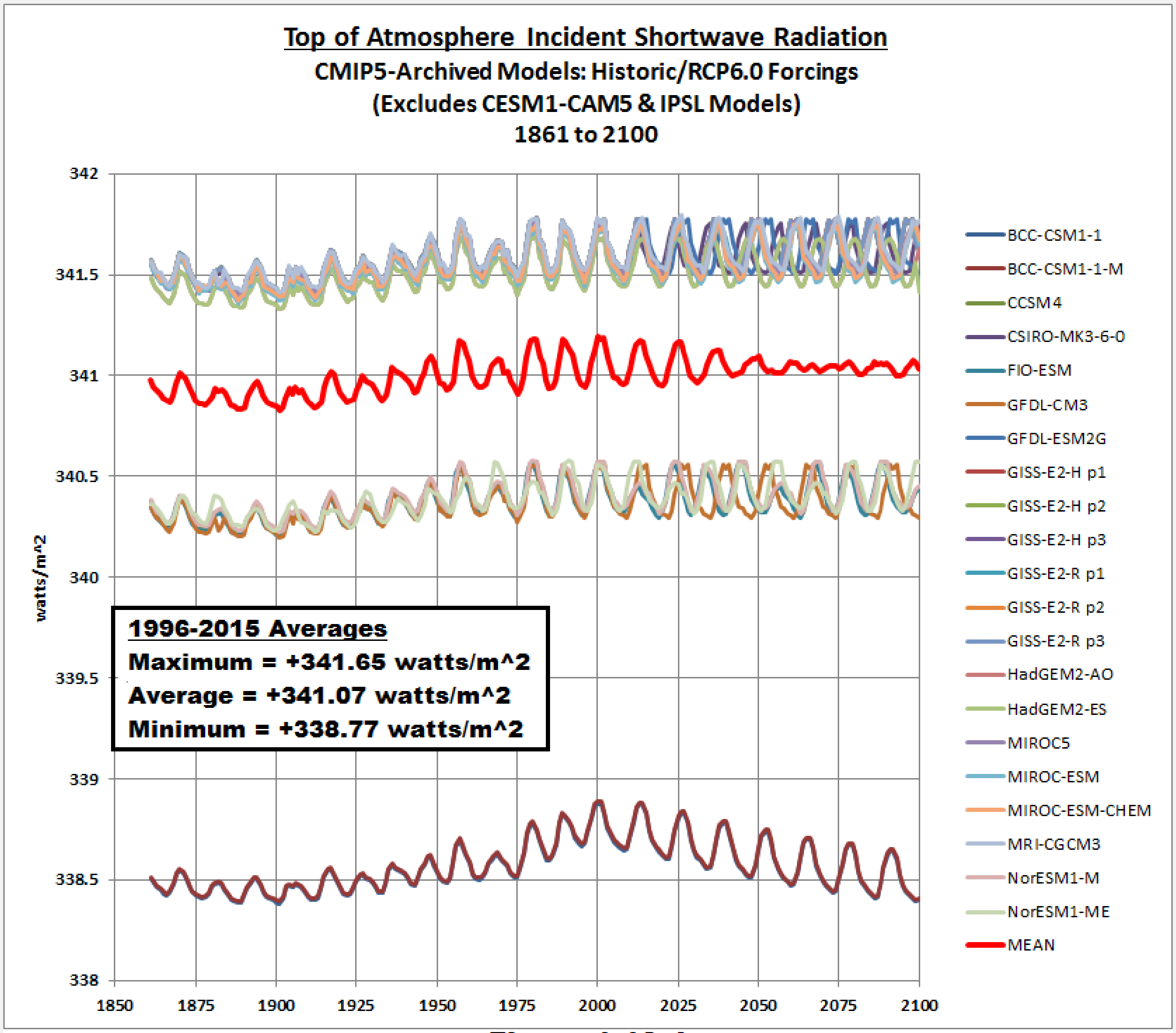

Top of Atmosphere Incident Shortwave Radiation
CMIP5-Archived Models: Historic/RCP6.0 Forcings
(Excludes CESM1-CAM5 & IPSL Models)
1861 to 2100
watts/m^2
342
341.5
341
340.5
340
339.5
339
338.5
338
1850
1875
1900
1925
1950
1975
2000
2025
2050
2075
2100
1996-2015 Averages
Maximum = +341.65 watts/m^2
Average = +341.07 watts/m^2
Minimum = +338.77 watts/m^2
BCC-CSM1-1
BCC-CSM1-1-M
CCSM4
CSIRO-MK3-6-0
FIO-ESM
GFDL-CM3
GFDL-ESM2G
GISS-E2-H p1
GISS-E2-H p2
GISS-E2-H p3
GISS-E2-R p1
GISS-E2-R p2
GISS-E2-R p3
HadGEM2-AO
HadGEM2-ES
MIROC5
MIROC-ESM
MIROC-ESM-CHEM
MRI-CGCM3
NorESM1-M
NorESM1-ME
MEAN

Figure 1.10-4

# # #

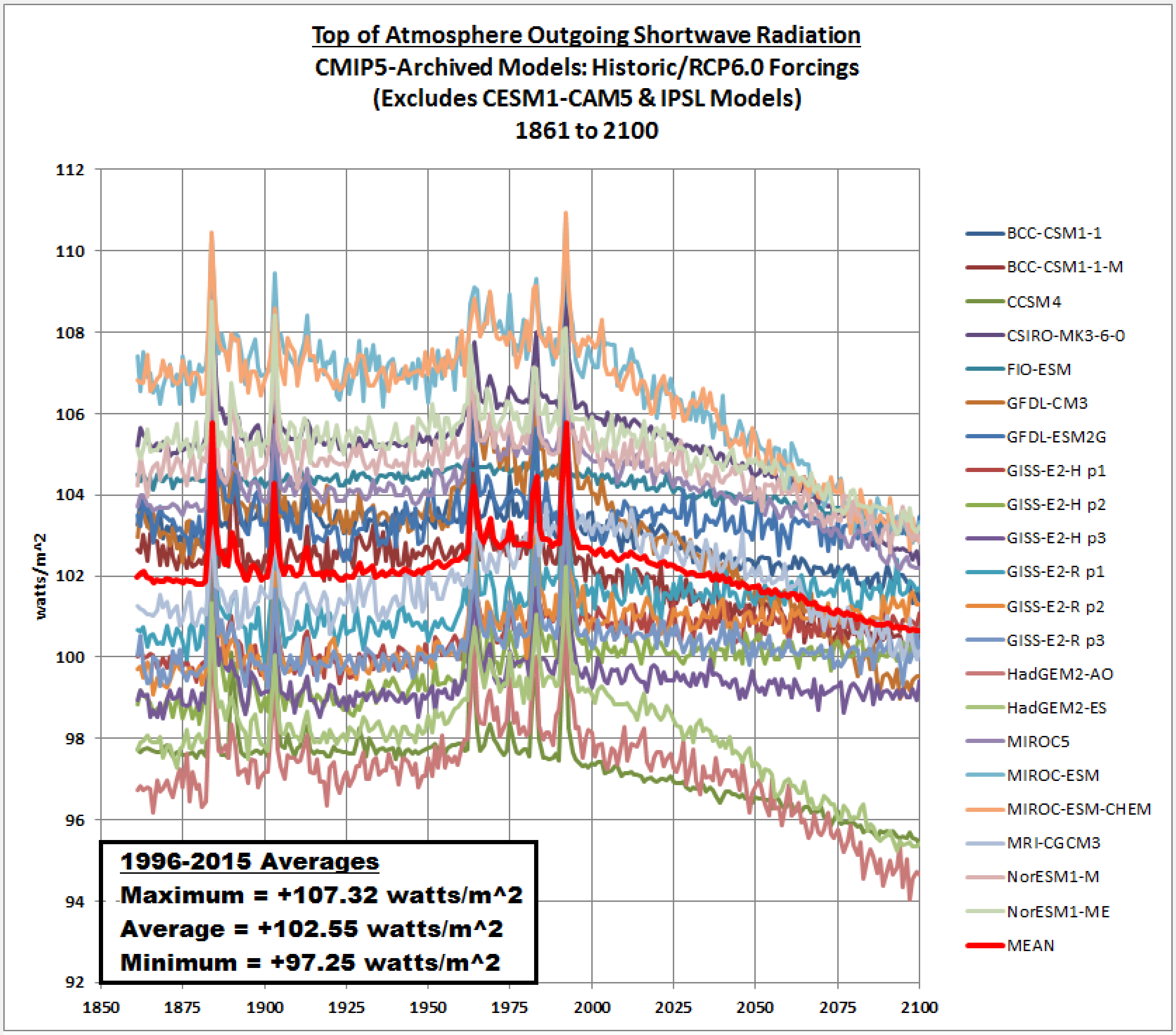

Top of Atmosphere Outgoing Shortwave Radiation
CMIP5-Archived Models: Historic/RCP6.0 Forcings
(Excludes CESM1-CAM5 & IPSL Models)
1861 to 2100
watts/m^2
112
110
108
106
104
102
100
98
96
94
92
1850
1875
1900
1925
1950
1975
2000
2025
2050
2075
2100
1996-2015 Averages
Maximum = +107.32 watts/m^2
Average = +102.55 watts/m^2
Minimum = +97.25 watts/m^2
BCC-CSM1-1
BCC-CSM1-1-M
CCSM4
CSIRO-MK3-6-0
FIO-ESM
GFDL-CM3
GFDL-ESM2G
GISS-E2-H p1
GISS-E2-H p2
GISS-E2-H p3
GISS-E2-R p1
GISS-E2-R p2
GISS-E2-R p3
HadGEM2-AO
HadGEM2-ES
MIROC5
MIROC-ESM
MIROC-ESM-CHEM
MRI-CGCM3
NorESM1-M
NorESM1-ME
MEAN

Figure 1.10-5

# # #

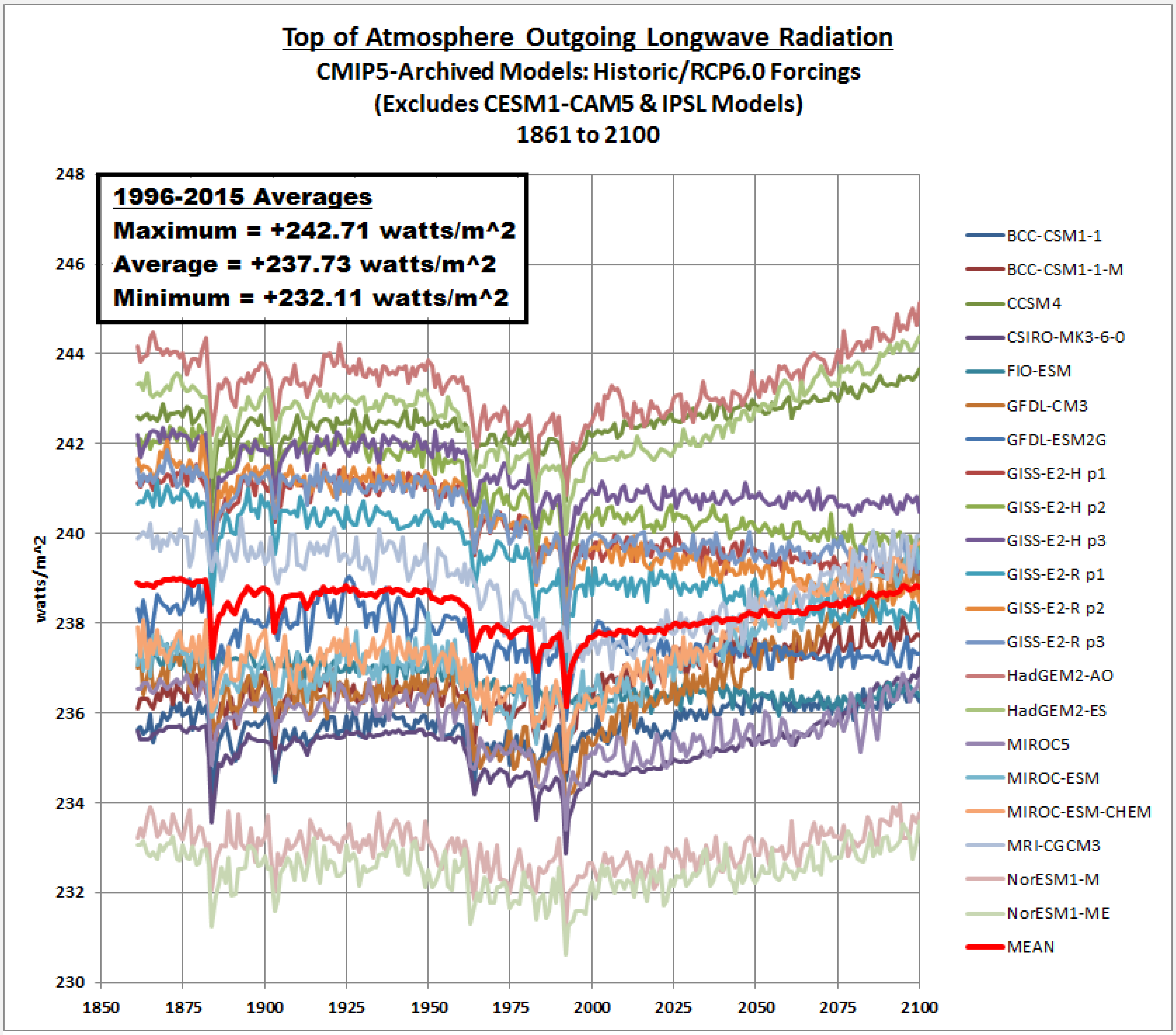


Figure 1.10-6

CLOSING FOR THE CLIMATE MODEL PORTION OF THIS CHAPTER

Let's start with a quote from the introduction of Trenberth et al. (2014) Earth's Energy Imbalance:

> *With increasing greenhouse gases in the atmosphere, there is an imbalance in energy flows in and out of the earth system at the top of the atmosphere (TOA): the greenhouse gases increasingly trap more radiation and hence create warming (Solomon et al. 2007; Trenberth et al. 2009). "Warming'' really means heating and extra energy, and hence it can be manifested in many ways. Rising surface temperatures are just one manifestation.*

Climate models have been programmed to raise modeled surface temperatures and subsurface ocean temperatures as the simulated energy imbalance increases in response to the numerical representations of man-made greenhouse gases and other climate forcings. Climate models have also been programmed to create number-crunched changes in numerous other metrics so that they show rising sea levels; decreasing sea ice, ice sheet and glacier mass; increasing precipitation; and so on as the energy imbalance increases. As a result, there is a general agreement among the models that, as the energy imbalance increases in value, the Earth will gain heat and extra energy…and that the heat and extra energy will be "manifested in many ways".

-However-

As we've illustrated and discussed in this chapter, looking at the three factors that make up the TOA energy imbalance, there is no agreement among the climate models on the values of past, present and future outgoing shortwave and longwave radiation. As a result, there is no agreement about:

- what caused the warming we've experienced to date,
- what will enhance any future warming, and
- what the absolute values of the energy imbalance were in the past, are presently and will be in the future.

Climate models have been programmed to show global warming and all of its manifestations in response to rising energy imbalance values. But modeling groups go through very different gyrations (by manipulating clouds?) with the two computer-calculated components of the Earth's energy budget at the top of the atmosphere in order to achieve that warming…which indicates there is no consensus on how Earth's atmosphere and oceans have responded in the past, are responding now, and will respond in the future to man-made greenhouse gases. No consensus whatsoever.

1.11 – We Can't Forget Sunlight

Sunlight is the ultimate driver of climate on Earth. In areas where clouds don't reflect sunlight back into space, solar radiation passes through the atmosphere to warm the surface of the planet…and passes into the oceans to depths of 100 meters or so (about 330 feet), warming the oceans, though most of the sunlight is absorbed in the top 10 meters (about 33 feet).

The output of the sun varies a little, and these variations are known as the solar cycle. The solar cycle has a frequency of about 11 years. Sunspots have been used for centuries as an indicator of the variations in the Sun's output. More recently, satellites have measured the output of the sun at the top of the atmosphere since the late 1970s, and the amount to solar energy at the top of the atmosphere is approximately 1366 watts/m^2. See Figure 1.11-1 which presents one dataset of the annual average Total Solar Irradiance (TSI) in watts/m^2 from 1979 to 2012. TSI includes visible sunlight and solar radiation at other frequencies.

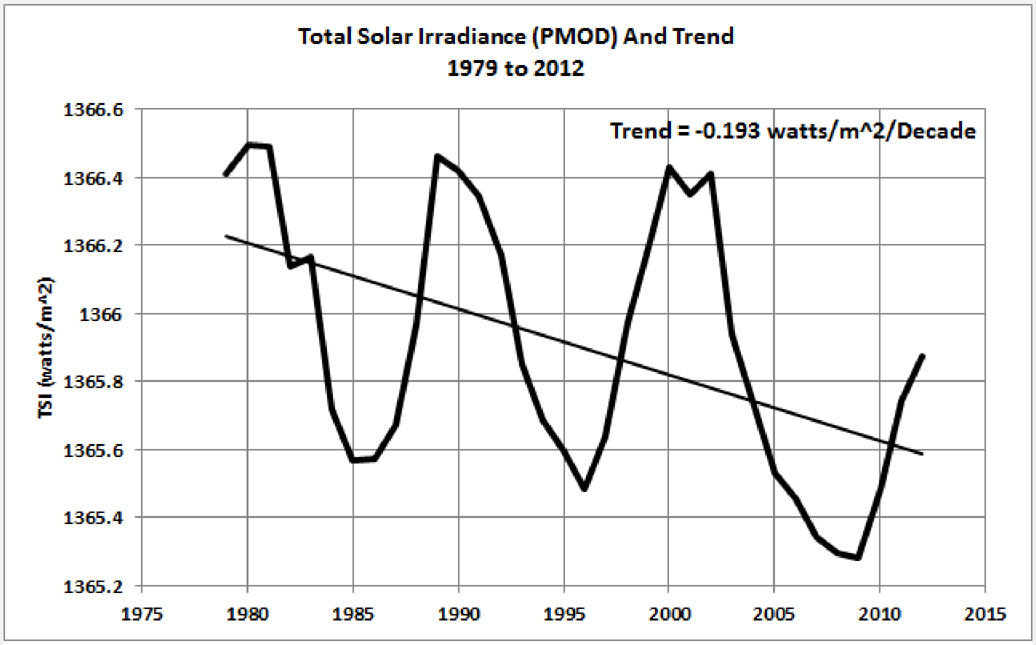


Figure 1.11-1

The source of this satellite-based Total Solar Irradiance data is PMOD ([Physikalisch-Meteorologisches Observatorium Davos – World Radiation Center]()). Total Solar Irradiance data are not the product of one satellite, continuously measuring the output of the sun. The useful life of some satellites may only be a decade. Therefore, the total solar irradiance data are a composite of measurements from numerous satellites. (See the top graph in the PMOD webpage here.)

There is even controversy about the output of the sun. Note the steady decline in the solar minimums (the low points in the solar cycles) above in Figure 1.11-1 above. Many solar physicists believe the decline in the minimums is caused by the decay of a satellite orbit. Those scientists believe there is less of a decline—one that is more in line with the decline in the number of sunspots at solar minimum. See Figure 1.11-2.

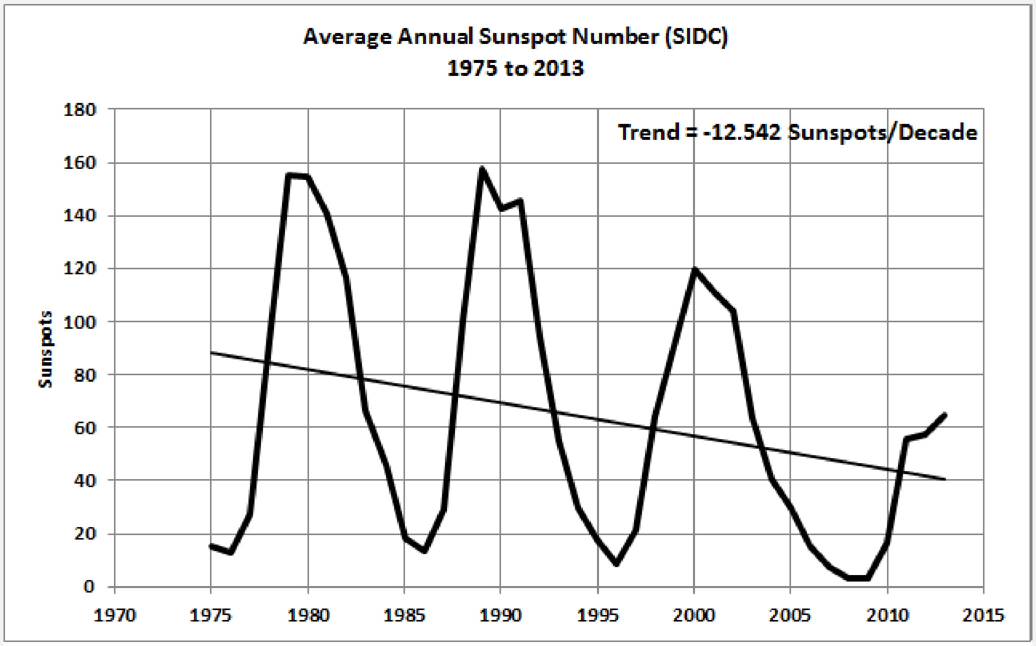


Figure 1.11-2

The sunspot data are the product of the Solar Influences Data Analysis Center (SIDC).

Climate scientists argue that variations in the sun's output could not have been the cause of the warming since the mid-1970s, because there had not been a sizable increase in total solar irradiance during that time. In fact, looking at the trend in total solar irradiance from the maximum of Solar Cycle 21 to Solar Cycle 23, as shown in Figure 1.11-3 below, total solar irradiance decreased slightly during that warming period that ran from the late-1970s to about the turn of the century.

And there's even controversy about the role of the sun in global warming and climate change. Climate scientists are not certain how the changes in the sun's output effect clouds and other factors. We'll avoid those debates in this discussion. I don't want to add any more confusion to a subject that may be somewhat complex for newcomers...except for one more thing.

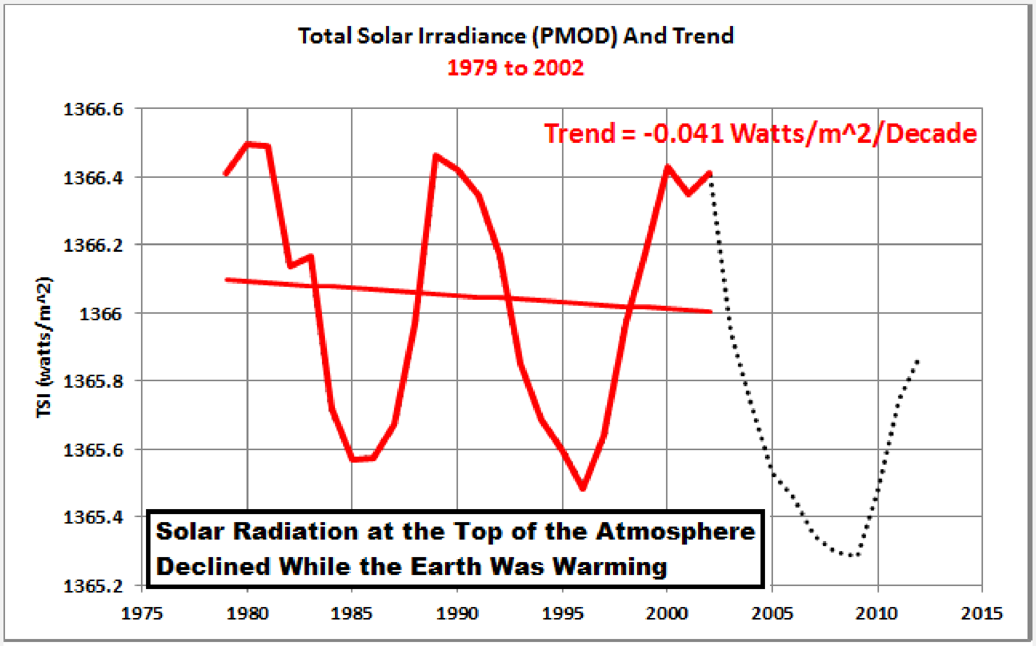


Figure 1.11-3

Satellites measure the amount of solar radiation at the top of the atmosphere, but our primary interest should be the amount of sunlight reaching the surface of the Earth—not how much sunlight is reaching the top of the atmosphere. If there was a small decrease in cloud cover during the recent warming period from the mid-1970s to about 2000, then the resulting increase in sunlight at the surface could explain a good part of the warming.

I presented Figure 1.11-4 in the Introduction as Figure Intro-20, and I'm showing it again now because it's important. Because there is very little observations-based data for the amount of sunlight reaching the Earth's surface, especially for the oceans, climate scientists have to estimate it with computer models that have other observations-based data as inputs. Those specialty climate models are called reanalyses. The NCEP-DOE Reanalysis-2 is a product of the NOAA National Centers for Environmental Predictions (NCEP) and the U.S. Department of Energy (DOE) . The NCEP-DOE Reanalysis-2 is supported by the 2002 paper NCEP-DOE AMIP-II Reanalysis (R-2) by Kanamitsu et al., which has been cited by several hundred other scientific papers. Quite surprisingly, the NCEP-DOE Reanalysis-2 shows a substantial increase the amount of sunlight reaching the Earth's surface (in scientific terms: downward shortwave radiation at the surface). See Figure 1.11-4.

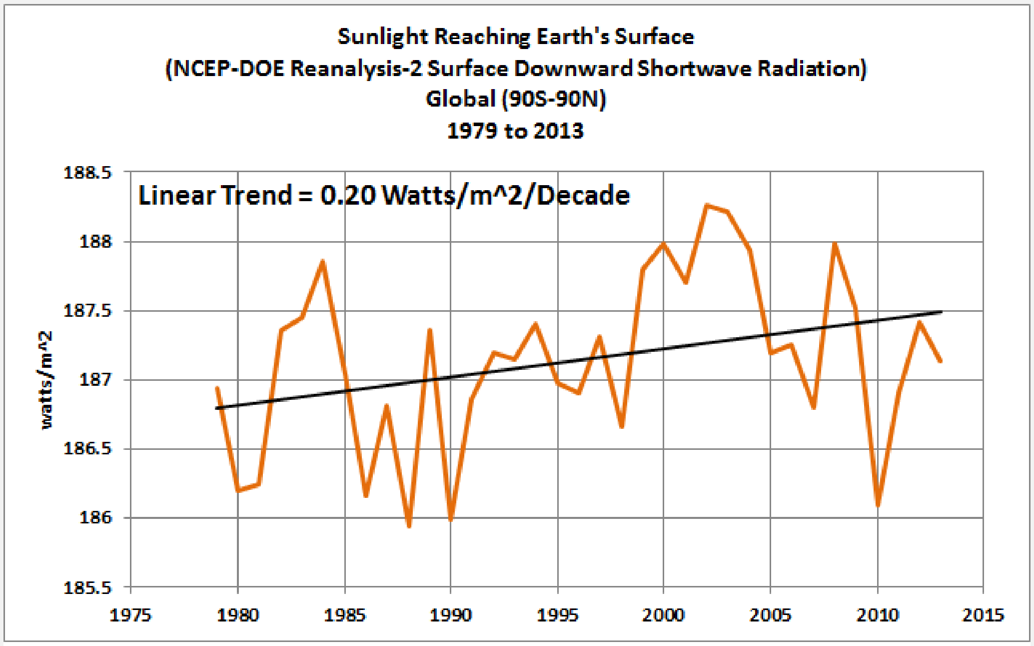


Figure 1.11-4

We'll discuss this numerous times throughout this book.

Basically, according to the NCEP-DOE Reanalysis-2, an increase in the amount of sunlight reaching the Earth's surface could have been a major contributor to the warming we've seen since the late 1970s.

1.12 – How Scientists Attributed Most of the Global Warming Since the Mid-1970s to Man-made Causes

One of the objectives of the climate science community under the direction of the IPCC has been to attribute most of the global warming since the mid-1970s to man-made causes. In other words, if Mother Nature was responsible for the warming, the political goal to limit the use of fossil fuels would have no foundation, and because the intent of the IPCC is to support political agendas, the climate science community had to be able to point to mankind as the culprit. The climate modelers achieved that goal using a few very simple tactics.

The first thing climate modelers did was they ignored the naturally occurring ocean-atmosphere processes that contribute to or suppress global warming. The climate models used by the IPCC still to this day cannot simulate those processes properly, and we'll illustrate that fact very plainly later in this book. Ignoring Mother Nature's contributions was the simplest and most-convenient way to show humans are responsible for the warming. The modelers also elected not to disclose this fact to the public when they presented their modeled-based attribution studies using the next tactic.

That tactic is a very simple and easy-to-understand way to falsely attribute most of the warming to mankind. The modelers had their climate model runs that showed virtual global surface temperatures warming in response to all the climate forcings that are used as inputs to the models. They then performed additional modeling experiments. Instead of using all of the climate forcings they typically include in their simulations of past climate, they only used the natural climate forcings of solar radiation and volcanic aerosols in the extra climate model runs. The flawed logic: if the models run with only solar radiation and volcanic aerosols (natural forcings) cannot simulate the warming we've experienced in the late 20th century, and if the models run with natural and anthropogenic forcings can simulate the warming, then the warming since the 1970s had to be caused by man-made greenhouse gases.

As an example, Figure 1.12-1 is a time-series graph that runs from 1880 to 2010. The solid brown curve shows the net radiative forcing of all forcings that are used as inputs to the climate models prepared by the Goddard Institute for Space Studies (GISS). They're from the Forcings in GISS Climate Model webpage, specifically the table here. (In Chapter 2.3, we will illustrate the forcings individually.) Also included in Figure 1.12-1 is the net of only the solar irradiance (sunlight) and stratospheric aerosols (sunlight-blocking volcanic aerosols), shown as the dark green dashed curve; they are considered naturally occurring forcings. As we can see, the group with all of the forcings shows a long-term increase, while the combined forcings from the sun and volcanos do not.

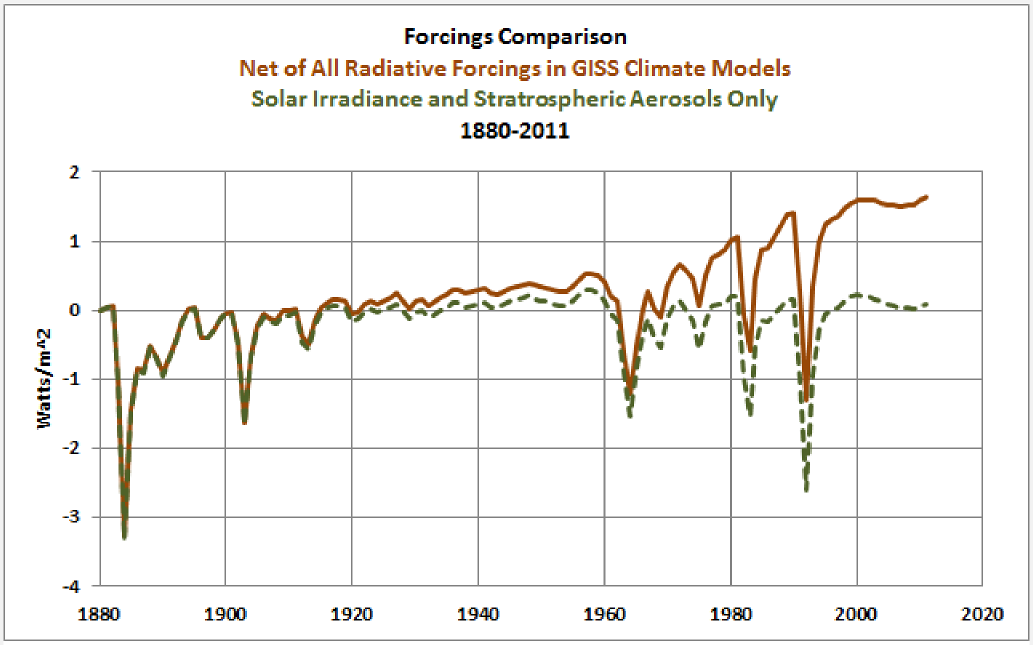


Figure 1.12-1

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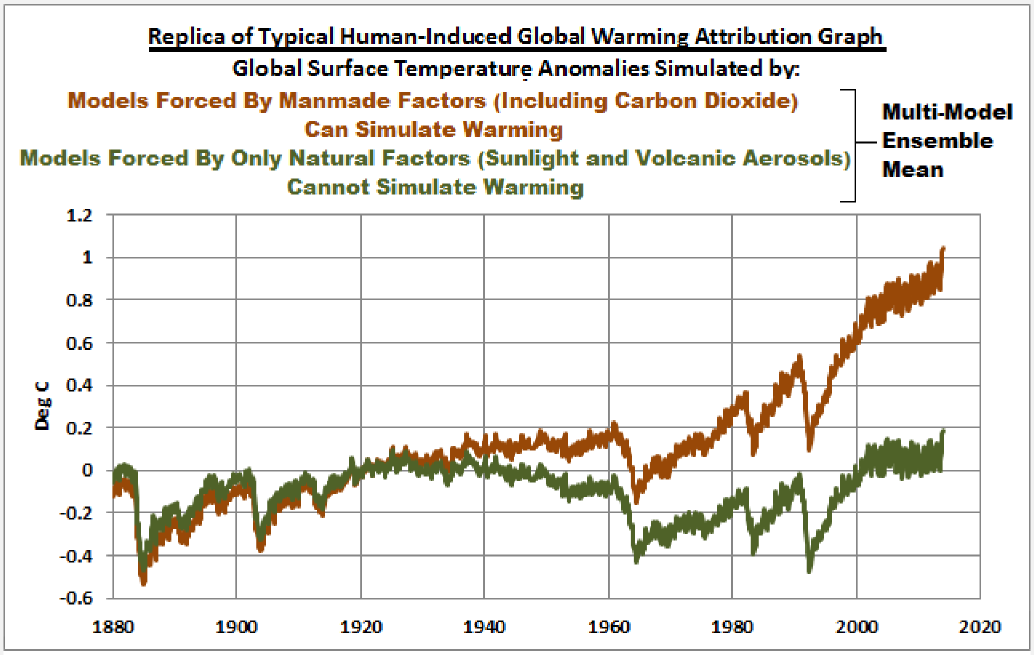


Figure 1.12-2

The climate scientists then ran the additional model simulations with only the natural forcings. They then compare the model simulations using natural and man-made forcings with the models run with the natural forcings only. An example of one of those comparisons is shown in Figure 1.12-2. The models run with man-made and natural forcings show considerable warming in the late 20th Century and the models run with only natural forcings do not show the warming.

Graphs similar to the one shown in Figure 1.12-2 can be found in the 4th and 5th Assessment Reports from the IPCC. One example is FAQ 10.1, Figure 1 from Chapter 10, Detection and Attribution of Climate Change: from Global to Regional of the IPCC's 5th Assessment Report (AR5). See my Figure 1.12-3. Note that the title of their FAQ 10.1 is "Climate Is Always Changing. How Do We Determine the Causes of Observed Changes?"

FAQ 10.1, Figure 1 from IPCC 5th Assessment Report

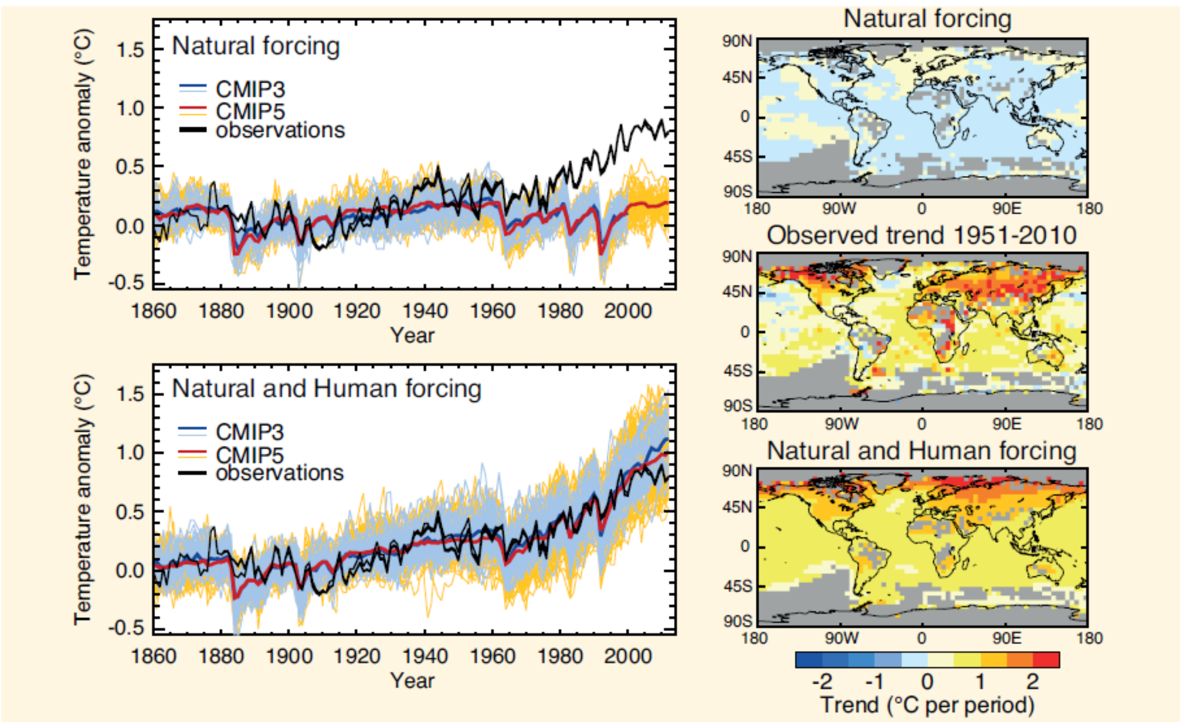


Figure 1.12-3

Note: The citation required by the IPCC for the use of their illustration is at the end of the chapter. [End note.]

About their FAQ10.1, Figure 1, the IPCC writes:

> *FAQ 10.1, Figure 1 illustrates part of a fingerprint assessment of global temperature change at the surface during the late 20th century. The observed*

change in the latter half of the 20th century, shown by the black time series in the left panels, is larger than expected from just internal variability. Simulations driven only by natural forcings (yellow and blue lines in the upper left panel) fail to reproduce late 20th century global warming at the surface with a spatial pattern of change (upper right) completely different from the observed pattern of change (middle right). Simulations including both natural and human-caused forcings provide a much better representation of the time rate of change (lower left) and spatial pattern (lower right) of observed surface temperature change.

Both panels on the left show that computer models reproduce the naturally forced surface cooling observed for a year or two after major volcanic eruptions, such as occurred in 1982 and 1991. Natural forcing simulations capture the short-lived temperature changes following eruptions, but only the natural + human caused forcing simulations simulate the longer-lived warming trend.

The caption for their FAQ 10.1, Figure reads:

***FAQ 10.1, Figure 1* |** *(Left) Time series of global and annual-averaged surface temperature change from 1860 to 2010. The top left panel shows results from two ensemble [sic] of climate models driven with just natural forcings, shown as thin blue and yellow lines; ensemble average temperature changes are thick blue and red lines. Three different observed estimates are shown as black lines. The lower left panel shows simulations by the same models, but driven with both natural forcing and human-induced changes in greenhouse gases and aerosols. (Right) Spatial patterns of local surface temperature trends from 1951 to 2010. The upper panel shows the pattern of trends from a large ensemble of Coupled Model Intercomparison Project Phase 5 (CMIP5) simulations driven with just natural forcings. The bottom panel shows trends from a corresponding ensemble of simulations driven with natural + human forcings. The middle panel shows the pattern of observed trends from the Hadley Centre/Climatic Research Unit gridded surface temperature data set 4 (HadCRUT4) during this period.*

For another example of this misguided, childish logic, see Figure 9.5 from their 4th Assessment Report. The text of AR4 Chapter 9 for that illustration reads (my brackets and boldface):

9.4.1.2 Simulations of the 20th Century

There are now a greater number of climate simulations from AOGCMs [Atmosphere-Ocean General Circulation Models] for the period of the global surface instrumental record than were available for the TAR [Third Assessment Report], including a greater variety of forcings in a greater variety of combinations. These simulations used models with different climate sensitivities,

> *rates of ocean heat uptake and magnitudes and types of forcings (Supplementary Material, Table S9.1).* ***Figure 9.5 shows that simulations that incorporate anthropogenic forcings, including increasing greenhouse gas concentrations and the effects of aerosols, and that also incorporate natural external forcings provide a consistent explanation of the observed temperature record, whereas simulations that include only natural forcings do not simulate the warming observed over the last three decades.***

As mentioned earlier, the logic behind this type of attribution is very simple, childishly simple. If models that include anthropogenic and natural forcings can simulate the warming, and if the models that include only natural forcings cannot simulate the warming, then the anthropogenic forcings must be responsible for the global warming.

But the logic is flawed—fatally flawed. There are naturally occurring ocean-atmosphere processes that can cause global surface temperatures to warm and cool without being forced to do so by man-made greenhouse gases. The climate models do not simulate those processes so they are not considered in attribution studies like this.

There's another way to look at this. One of the greatest climate-model failings is their inability to simulate naturally occurring ocean-atmosphere processes…like those associated with El Niño and La Niña events, like those associated with the Atlantic Multidecadal Oscillation. We'll present those failings later in the book. So like anyone trying to market a flawed product, the crafty IPCC turned those failings into a positive by ignoring them in their attribution studies.

NOTE:

The citation required by the IPCC for the use of their FAQ 10.1, Figure 1:

Bindoff, N.L., P.A. Stott, K.M. AchutaRao, M.R. Allen, N. Gillett, D. Gutzler, K. Hansingo, G. Hegerl, Y. Hu, S. Jain, I.I. Mokhov, J. Overland, J. Perlwitz, R. Sebbari and X. Zhang, 2013: Detection and Attribution of Climate Change: from Global to Regional. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

1.13 – The Roles of the Oceans

The oceans stabilize climate, and they also make the Earth's land surfaces inhabitable. That is, without the oceans, the Earth would be a much different planet. Additionally, the oceans are responsible for almost all of the water vapor in the atmosphere, and, through coupled ocean-atmosphere processes, the oceans contribute to weather on Earth.

It is often noted that the top 3 meters (about 10 feet) of the oceans can hold as much heat as the atmosphere. See the NOAA Pacific Fisheries Environmental Laboratory (PFEL) webpage here. Now consider that the average depth of the oceans, according to the NOAA National Geophysical Data Center webpage here, is 3688 meters (about 12,100 feet). Because of this monumental capacity to store heat, the oceans are also said to have a stabilizing or damping effect on climate.

One way to show this damping effect is by comparing the annual cycle in the surface temperatures of the oceans (the dataset is known as sea surface temperatures) with the annual cycle in the land surface air temperatures, using the data for the Northern or the Southern Hemispheres. That way we can compare how the sun impacts land and ocean surface temperatures in each hemisphere as the year runs through the seasons.

Land surface air temperature data are not available in absolute form from the three primary suppliers of global temperature products (GISS, NCDC, and UKMO). They only provide their global temperature products in anomaly form. So for this discussion we have to use a reanalysis (the output of a specialized computer model) for the comparisons. That reanalysis is called GHCN-CAMS. Sea surface temperature data are available in absolute form, and for this discussion we're using the NOAA Optimum Interpolation sea surface temperature data, version 2 (also known as Reynolds OI.v2). It is a satellite-enhanced dataset, meaning it relies on data from ship inlets, buoys and satellites. Both the land surface air temperature output from the GHCN-CAMS reanalysis and the Reynolds OI.v2 sea surface temperature data are available through the KNMI Climate Explorer.

Keep in mind when viewing the following graphs that we're looking at sea surface temperatures, not the temperatures of the oceans to depth. As far as I know, the subsurface temperature data for the oceans are not available as absolute temperatures in an easy-to-use format anywhere on the web. So we're really not seeing the true damping effect of the oceans in the following exercise.

Figure 1.13-1 presents the monthly land surface air temperatures and sea surface temperatures for the Northern Hemisphere over the course of a year, based on the average monthly temperatures for the 30-year period of 1984 to 2013.

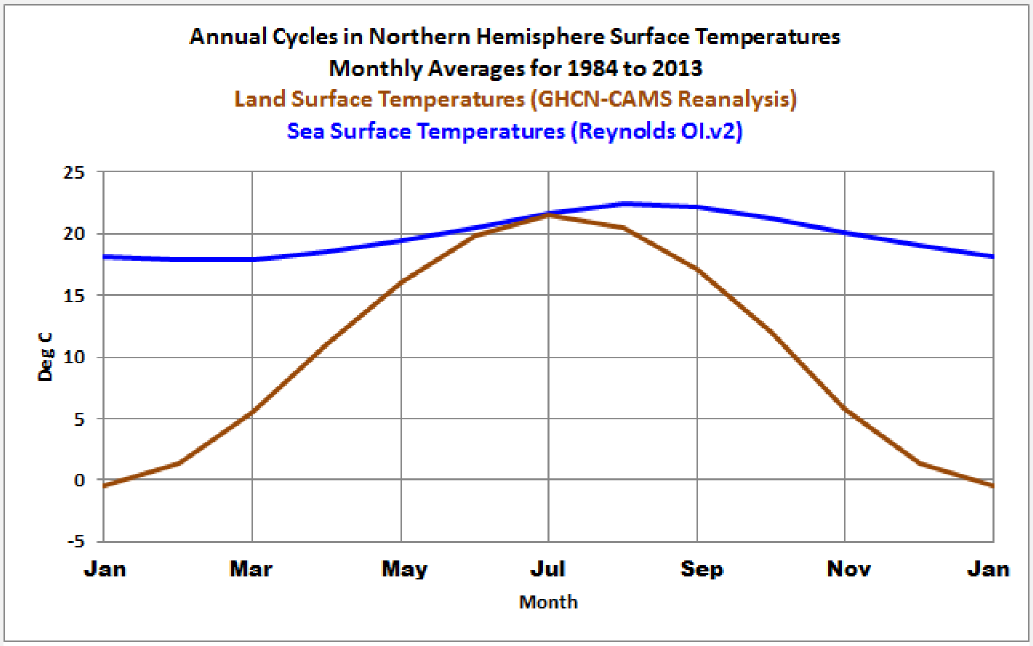


Figure 1.13-1

The annual cycle in Northern Hemisphere land surface air temperatures spans almost 22 deg C (almost 40 deg F) from approximately -0.5 deg C (about 31 deg F) in January to about 21.5 deg C (71 deg F) in July. On the other hand, the ocean surfaces of the Northern Hemisphere are coldest in February, lagging land surface temperatures by a few weeks. Likewise they are at their warmest a few weeks later than land surface temperatures during the summer also. Also note how the surfaces of the Northern Hemisphere oceans are much warmer and they vary much less from winter to summer than land surface air temperatures. The annual cycle in Northern Hemisphere sea surface temperatures spans only 4.5 deg C (about 8.0 deg F) from approximately 18 deg C (about 64 deg F) in February to about 22.5 deg C (72 deg F) in August.

The average annual Northern Hemisphere sea surface temperature over the past 30 years is about 20 deg C (about 68 deg F) while the average land surface air temperature is much colder at about 11 deg C (52 deg F).

Figure 1.13-2 presents the seasonal cycles in land surface air temperature and sea surface temperature for the Southern Hemisphere. You'll note that the sea surface temperature cycle lags the land surface air temperature cycle and that, once again, land surface air temperatures are much cooler and have much more variability than sea surface temperatures.

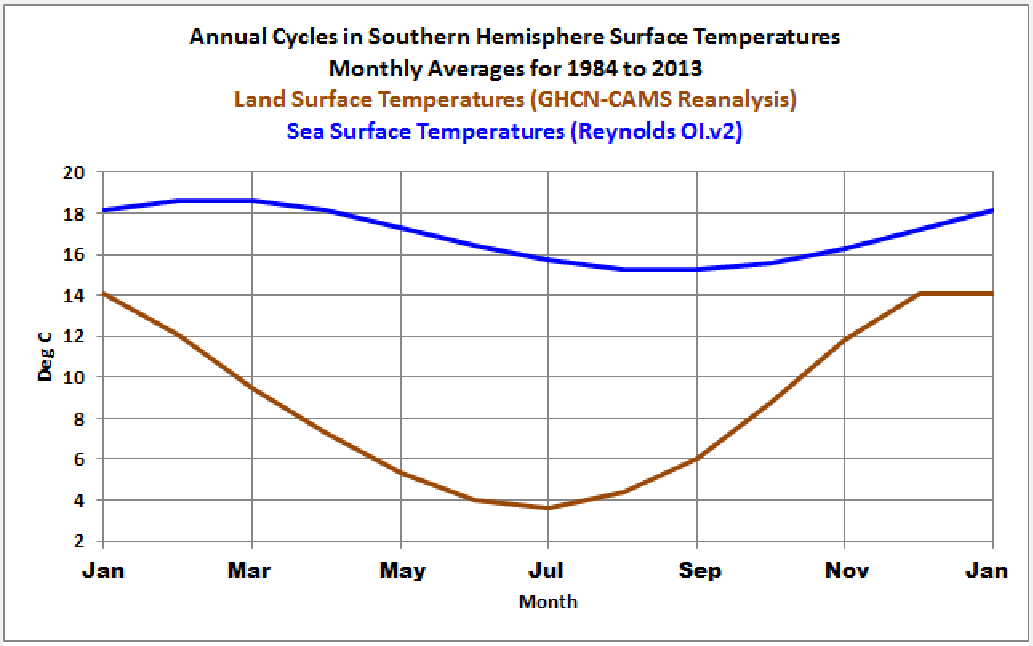


Figure 1.13-2

# # #

Annual Maximum, Minimum & Mean of Global and Hemispheric Surface Temperatures

Based on Monthly Averages from 1984 to 2013

Land Surface Air Temperatures Based on GHCN/CAMS Reanalysis

Sea Surface Temperatures Based on Reynolds OI.v2 Data

	Northern Hemisphere		Southern Hemisphere		Global	
Metric	Deg C	Deg F	Deg C	Deg F	Deg C	Deg F
Monthly Land Surface Air Temperature						
Annual Maximum	21.5	70.7	14.1	57.4	15.6	60.0
Annual Minimum	-0.4	31.2	3.7	38.6	3.9	39.0
Delta T (Annual Max. Minus Annual Min.)	22.0	39.5	10.5	18.8	11.7	21.0
Annual Mean	11.0	51.7	8.4	47.1	9.9	49.7
Monthly Sea Surface Temperature						
Annual Maximum	22.4	72.3	18.7	65.6	18.4	65.1
Annual Minimum	17.8	64.1	15.3	59.5	18.0	64.4
Delta T (Annual Max. Minus Annual Min.)	4.6	8.2	3.4	6.1	0.4	0.7
Annual Mean	19.9	67.9	16.9	62.4	18.2	64.8

Table 1.13-1

Table 1.13-1 compares the annual global and hemispheric land surface air temperatures and sea surface temperature:

- maximums
- minimums

- temperature differences (delta T) between the maximums and minimums
- mean

Like the graphs, the values are based on the monthly averages the period of 1984 to 2013.

And Figure 1.13-3 shows the seasonal cycles in the global data. The land surface area in the Northern Hemisphere is much greater than in the Southern Hemisphere, so the seasonal cycle in the Northern Hemisphere dominates. Note also how small the global seasonal cycle is for sea surface temperatures compared to land surface air temperatures.

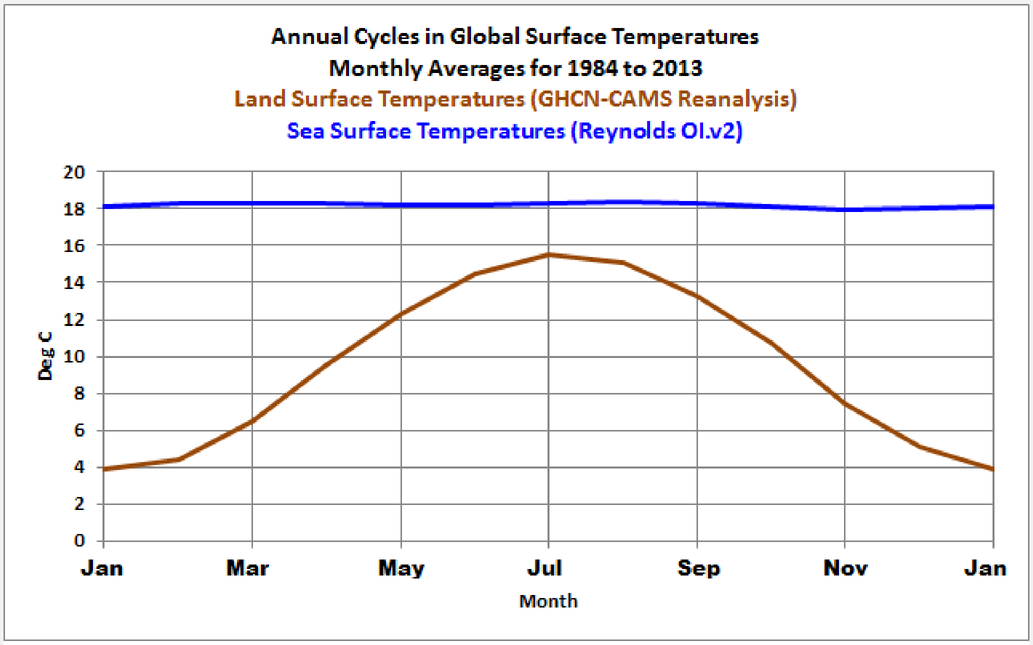


Figure 1.13-3

Keep in mind also that the oceans are said to have their own greenhouse-like effect. As noted earlier, sunlight can penetrate into the oceans to depths of about 100 meters (about 330 feet), but most sunlight is absorbed in the top 10 meters (about 33 feet). Sunlight entering the oceans warms them. But the oceans can only release heat at the surface—and—the oceans release most of their heat through evaporation. It is often said the oceans, like humans, cool themselves by sweating.

IF OUR PLANET WAS COVERED BY ALL OCEANS OR ALL LAND, WHICH EARTH WOULD BE WARMER?

Referring back to Table 1.1.13-1, the average surface temperature of the global oceans for the past 30 years is about 18 deg C (about 65 deg F), while the average global land surface air temperature is about 10 deg C (about 50 deg F) or approximately 8 deg C

(15 deg F) cooler. The late John L. Daly noted the same difference in his article The Deep Blue Sea:

> ***Which "Earth" would be warmer?***
>
> *The ocean-covered earth would be warmer at the ocean surface than the land-covered one, simply due to the oceans ability to collect radiant heat more efficiently than it can re-radiate it. This is because the ocean collects solar radiation in three dimensions. To maintain thermal equilibrium, the oceans must re-radiate an equal amount in the form of infra-red radiation, but can only do so from the two-dimensional surface of the ocean. This imbalance would force up the ocean temperature in order that the surface radiation alone could balance off the solar radiation being collected by both the surface and deeper waters simultaneously.*
>
> *The land planet, by contrast, would absorb radiant heat in the daytime, and re-radiate it all just as quickly at night.*
>
> *It is difficult to estimate how much warmer the ocean planet would be, but comparisons of data between the larger absorbed radiation and the much smaller re- emitted infra-red from the oceans, suggest that the ocean planet could be about 8 to 10 degrees warmer than the land planet. The key would be the ocean planets' inability to radiate as much heat from the ocean surface at night as it collected to 100 metres depth in the daytime.*
>
> *In reality of course, the real earth is a mixture of the two, with oceans being predominant covering over 70% of the planet and with a complex atmosphere of many gases. This being the case, we can estimate that the Earth is about +6 deg warmer, simply due to the radiative imbalance in the ocean. Fortunately, the real oceans can also cool themselves by evaporation and direct heat exchange with the atmosphere.*
>
> *It might be thought that infra-red back-radiation from the atmosphere to the oceans, ie. the greenhouse effect, would be a major net heat input to the oceans. However, as fig. 1 shows, infra-red energy only penetrates the first few millimetres of the water surface, most of it being then tossed straight back to the atmosphere due to surface evaporation. The remarkable constancy of tropical temperatures, in spite of wide fluctuations in energy inputs, particularly the 7% variation in solar radiation due to the earth's elliptical orbit, attests to this effect.*
>
> *The relevance of these imaginary scenarios is that climate modelers are assuming that the natural greenhouse effect warms the earth a full 33 deg from -18 to +15 deg. This 33 deg assumption then sets the base-line for many other*

calculations about the impact of additional greenhouse gases. As we can see, the albedo error alone cuts this back from 33 to 20 deg, while the radiation imbalance of the ocean takes a further possible 6 degrees from this to make the natural greenhouse effect worth only about 14 deg, not 33 deg as assumed.

Even though the oceans have a radiation imbalance, their overall heat budget in the real world allows latent heat removal through evaporation, and direct contact with the atmosphere, to remove most of the surplus heat, (creating atmospheric water vapour in the process). Were it to be left to radiation alone to establish thermal equilibrium, the oceans would become significantly warmer, perhaps even really hot in tropical regions.

The Earth would be a much different place if 70% of it wasn't covered mostly by oceans. There are numerous other factors that would have to be taken into account if there were no oceans. The primary one is there would much less water vapor in the atmosphere. And with less water vapor, the greenhouse effect would be much different.

The NOAA Ocean Service Education website called The Ocean's Role in Weather and Climate is a good starting point for additional fundamental information. NASA's OceanMotion website is another excellent reference for the role of Earth's oceans.

THE OCEANS ALSO STORE ENERGY FROM THE SUN AND OCCASIONALLY RELEASE IT TO THE ATMOSPHERE

As stated a few times, sunlight penetrates and warms the oceans to depths of about 100 meters (330 feet), though most of the sunlight is absorbed within the top 10 meters (33 feet) or so. But the oceans can only release that heat at the surface, and they release that heat primarily through evaporation. So the oceans can store heat from the sun, and as long as the associated warm water does not reach the surface, the oceans will continue to store that heat from the sun.

Nature has devised a process to periodically release that sunlight-created heat from the ocean to the atmosphere and to redistribute the associated warm water within the oceans. And the spectacular outcome of that process is commonly referred to as an El Niño. Sunlight-warmed water, which had been stored below the surface of the tropical Pacific, is released from below the surface and spread across the surface of the tropical Pacific during an El Niño. Because the surface of the tropical Pacific is now covered by that additional warm water, the tropical Pacific releases more heat than normal to the atmosphere. And it's a monstrously large amount of heat. The El Niño does not consume all of the warm water, so at the end of the El Niño, the leftover warm water is redistributed from the tropical Pacific to nearby parts of the oceans…through surface and subsurface ocean currents.

Nature has also developed a way to replenish the warm water released by an El Niño. And that replenishment phase can take place during a La Niña. Without getting into a lot of detail at this time, a La Niña accomplishes this by reducing cloud cover over the tropical Pacific, which allows more sunlight to warm the tropical Pacific to depth.

So the oceans have processes through which they can release heat periodically to the atmosphere, and then recharge the lost heat by allowing more sunlight than normal to heat the tropical Pacific Ocean.

The North Atlantic has an additional mode of natural variability called the Atlantic Multidecadal Oscillation. During some periods of 2 to 4 decades, the surface of the North Atlantic warms at a rate that is much faster than the rest of the global oceans. The North Atlantic is contributing to global warming at those times. During other multidecadal periods, the surface of the North Atlantic can warm much slower than the rest of the global oceans, and even cool. The North Atlantic is suppressing global warming during those periods.

Not too surprisingly, because climate research has been focused on greenhouse gases, primarily carbon dioxide, climate models still cannot simulate the sunlight-fueled recharge-discharge-redistribution processes associated with El Niño and La Niña events. And they cannot simulate the variations in the surface temperatures of the North Atlantic known as the Atlantic Multidecadal Oscillation.

Consider those deficiencies for a moment. That would be like trying to study and predict the growth of the money in numerous bank accounts without monitoring the sources of deposits, withdrawals and transfers. It cannot be done.

OBSERVING DEFICIENCIES

"Observing deficiencies" is one of the headings from the testimony of Dr. Raymond W. Schmitt of the Woods Hole Oceanographic Institution, when he appeared before the U.S. Senate Committee on Commerce, Science and Transportation back in 2000. Dr. Schmitt was asking the Senate to help fund the ARGO program. See the WHOI webpage titled The Ocean's Role in Climate. Dr. Schmitt writes (my boldface):

> ***Observing Deficiencies***
> *While we have in place a system for monitoring El Nino, we have no such ability to observe the motions of thermal anomalies in the mid- and high latitude oceans. Nor do we monitor the salt content of ocean currents, to determine the potential for deep convection or to help understand the vast water cycle over the oceans. But new technology, the vertically profiling ARGO float (Figure 4.), promises to give us the data we need to* ***begin to understand*** *this largest component of the global water cycle. These are like weather balloons for the*

> *ocean, drifting at depth for 10 days then rising to the surface to report profiles of temperature and salinity to a satellite. They then resubmerge for another 10 day drift, a cycle to be repeated 150 times or more. The distance traveled between surfacings provides a measure of the currents at the depth of the drift. The ARGO program (http://www.argo.ucsd.edu/) is an international plan to maintain a global distribution of ~3000 floats as a core element of a Global Ocean Observing System (Figure 5.) [Not included.]. Other parts of the system involve fixed sites with moored buoys and underwater profilers that record temperature and salinity all the way to the bottom of the ocean. These new technologies will give us the data we need to* ***begin to decipher*** *the complex climate phenomena we know to be operating in the ocean. Science is the process of testing ideas against observations, and failure to make the observations is an abandonment of the scientific process.*

Now, let's ponder that a minute. I've boldfaced "begin to understand" and "begin to decipher" for reasons that should be obvious. In 2000, Dr. Schmitt was asking congress to supply funds for the ARGO program. He was successful. The ARGO floats were deployed and had reasonable coverage of all oceans by 2003. Full coverage of the oceans was achieved a couple of years later. Then it was discovered (believed) that some of the sensors were defective, because the oceans were shown to be cooling. So adjustments were made to show warming.

Sea **surface** temperature records indicate there are long-term, naturally occurring variations in surface temperatures of the North Atlantic and North Pacific Oceans. We have reasonably complete surface temperature data for the Northern Hemisphere oceans since about 1900. A full "cycle" of those variations in **surface** temperatures takes 50 to 80 years. So in order to fully comprehend the interrelationship between the surface and subsurface temperatures of the oceans, there would have to be subsurface temperature and salinity data for at least one complete 50-to-80-year cycle, preferably two. But we have only a decade of corrected subsurface temperature and salinity data. Yet, we're told the science is settled, when, in fact, the climate science community still has a very limited understanding of the processes that drive subsurface ocean weather and climate.

We'll return to Dr. Schmitt's testimony in an upcoming chapter in this section.

MOST OF THE WATER VAPOR IN THE ATMOSPHERE COMES FROM THE OCEANS

We briefly mentioned this in this chapter, but it's an important role of the oceans so let's mention it again.

Most of the water vapor in Earth's atmosphere comes from the surfaces of the oceans. See the UCAR Introduction to the Atmosphere webpage for confirmation.

Logic dictates that as the ocean surfaces warm for whatever reason (both natural or man-made causes), the ocean surfaces release more moisture to the atmosphere through evaporation. And as the atmosphere warms, it can hold more moisture.

SUMMARY

The oceans moderate surface temperatures on Earth, and because the oceans are responsible for most of the water in the atmosphere, they also are the primary source of the water we see as precipitation over land surfaces in all its forms.

Unfortunately, we have been monitoring subsurface temperature and salinity, for only the top half of the oceans, for all ocean basins, in a reasonably spatially complete fashion, for a little over a decade. That's it…a decade. And because some subsurface ocean "weather" events take place on decadal and multidecadal timeframes, we have little data-based understanding of how the oceans can contribute to global warming and climate change. So please consider that sad fact the next time someone says the science behind global warming is settled. You'll laugh…just as I do every time I see someone make that claim.

1.14 – What Is Ocean Heat Content?

We briefly mentioned ocean heat content during our discussions of radiative imbalance in Chapter 1-10. Ocean heat content portrays the change with time in the amount of heat being stored in the oceans. It is an important climate metric because the atmosphere has a very small capacity to store heat. In Chapter 3 – Observations: Oceans of the IPCC's 5th Assessment Report, they list the estimated percentages of the Earth's heat gain over the period of 1971 to 2010. (See Box 3.1 on page pdf 11 of 62.):

> *Ocean warming dominates the total energy change inventory, accounting for roughly 93% on average from 1971 to 2010 (high confidence). The upper ocean (0-700 m) accounts for about 64% of the total energy change inventory. Melting ice (including Arctic sea ice, ice sheets and glaciers) accounts for 3% of the total, and warming of the continents 3%. Warming of the atmosphere makes up the remaining 1%.*

To put those percentages in perspective, refer to the pie chart in Figure 1.14-1.

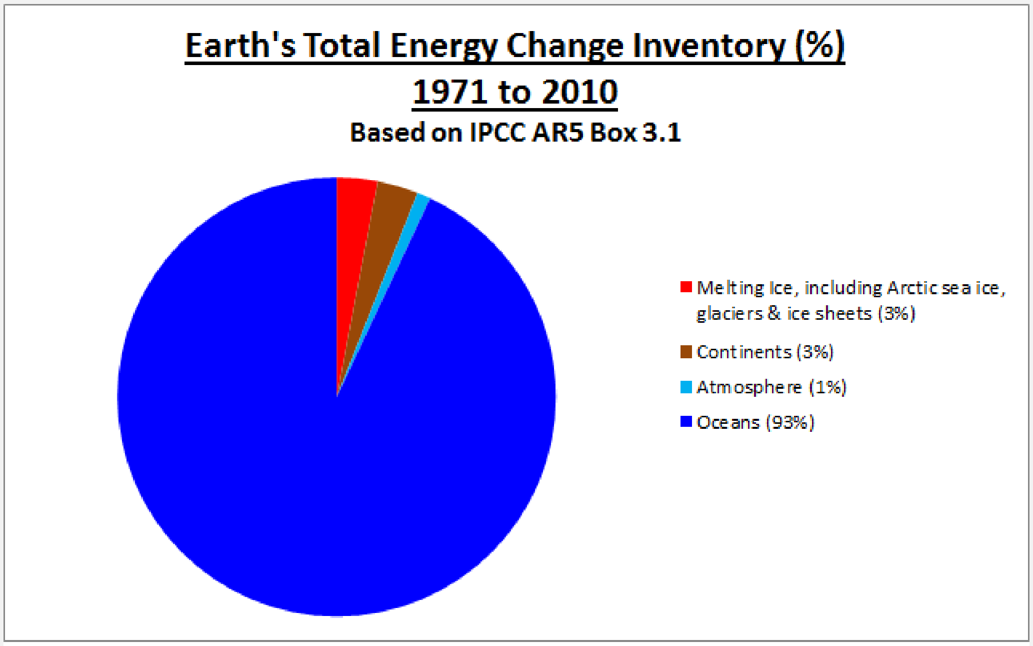


Figure 1.14-1

It's very obvious why the change in the ocean heat content is very important to the hypothesis of human-induced global warming. If the oceans could be shown to have warmed naturally, or if the data do not show the oceans accumulating heat, then the impacts of man-made greenhouse gases are much smaller than claimed by climate scientists.

Ocean heat content is calculated from subsurface temperatures and salinity readings at various depths.

THE TEMPERATURE COMPONENT

Figure 1.14-2 presents the quarterly vertically averaged temperature anomaly data for the global oceans, from the NOAA National Oceanographic Data Center (NODC), for the depths of 0-100 meters (0-328 feet), 0-700 meters (0-2300 feet), and 0-2000 meters (0-6560 feet). The world's oceans are deeper than 2000 meters. In fact, according to the NOAA National Geophysical Data Center (NGDC) webpage Volumes of the World's Oceans from ETOPO1, the average depth of the global oceans is 3688 meters (about 12,100 feet). But the ARGO floats (that have been in use since the early 2000s) only reach depths of 2000 meters…a little more than half (54% of the average depth).

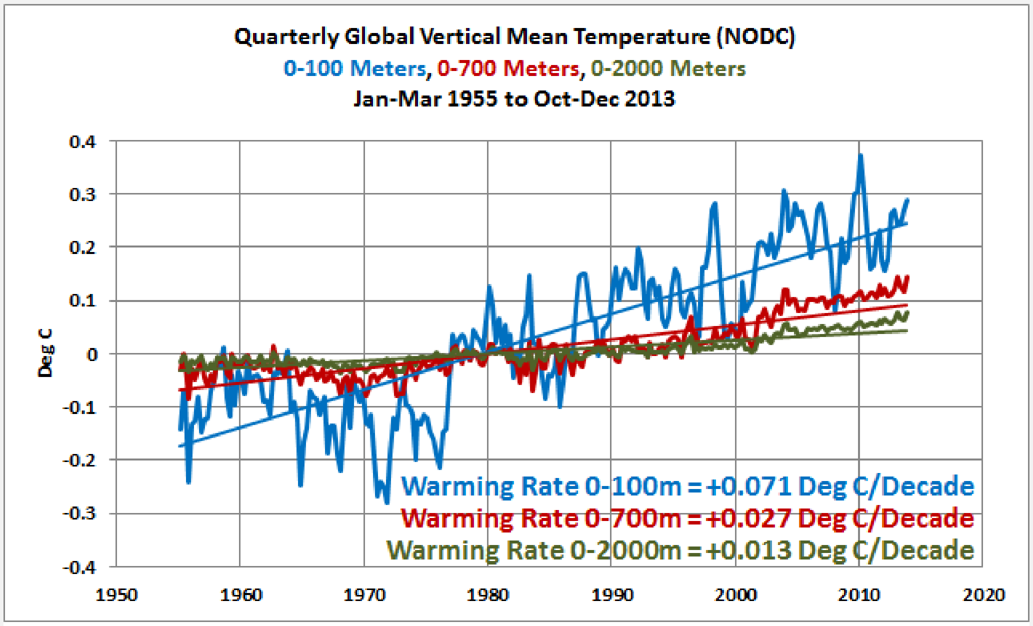


Figure 1.14-2

The vertically averaged temperature data from the NODC are available through their webpage here. The data are supported by the Levitus et al. (2012) paper World ocean heat content and thermosteric sea level change (0–2000 m), 1955–2010.

According to the NODC's data, and based on the linear trends, the global oceans to depths of 100 meters (about 328 feet) have warmed approximately 0.42 deg C (about 0.75 deg F) from 1955 to 2013. To 700 meters (about 2300 feet), the world's oceans have warmed considerably less: about 0.16 deg C (about 0.29 deg F) in that time. And for the depths of 2000 meters (about 6560 feet) the oceans have warmed very little from

1955 to 2013, less than 0.08 deg C (about 0.14 deg F). That means, while more than 90% of the "total energy change inventory" is being stored in the oceans, it has only caused the oceans to depths of 2000 meters to warm 0.08 deg C (about 0.14 deg F) in 59 years (1955 to 2013). And then there's the question, was the warming due to natural processes or due to man-made greenhouse gases? When we break the global data down into logical subsets later in this book, you may be surprised by the answer.

Now consider that we're only monitoring the temperatures of roughly the top half of the oceans (54%). If we assume there has been no measureable warming below 2000 meters, then the warming is only about 0.04 deg C from 1955 to 2013. That's read four one-hundredths of a degree C.

THE SALINITY COMPONENT

Now, let's take a look at the salinity portion (the saltiness of the oceans) of the NODC's ocean heat content data. We mentioned how poorly temperatures were sampled before the ARGO era in Chapter 1-10, and we'll discuss it later, in detail, in the upcoming Part 2 of this book. The sampling is far worse for salinity. The ocean salinity measurements are so sparse prior to 2005 that the NODC only presents the vertically averaged salinity data in sequential 5-year blocks called pentads. Since 2005, salinity has also been measured by the ARGO floats so the NODC presents the salinity data in quarterly and annual formats then. The salinity data from the NODC are supported by Antonov et al. (2010) World Ocean Atlas 2009, Volume 2: Salinity. And the salinity data are available from the NODC through their webpage here.

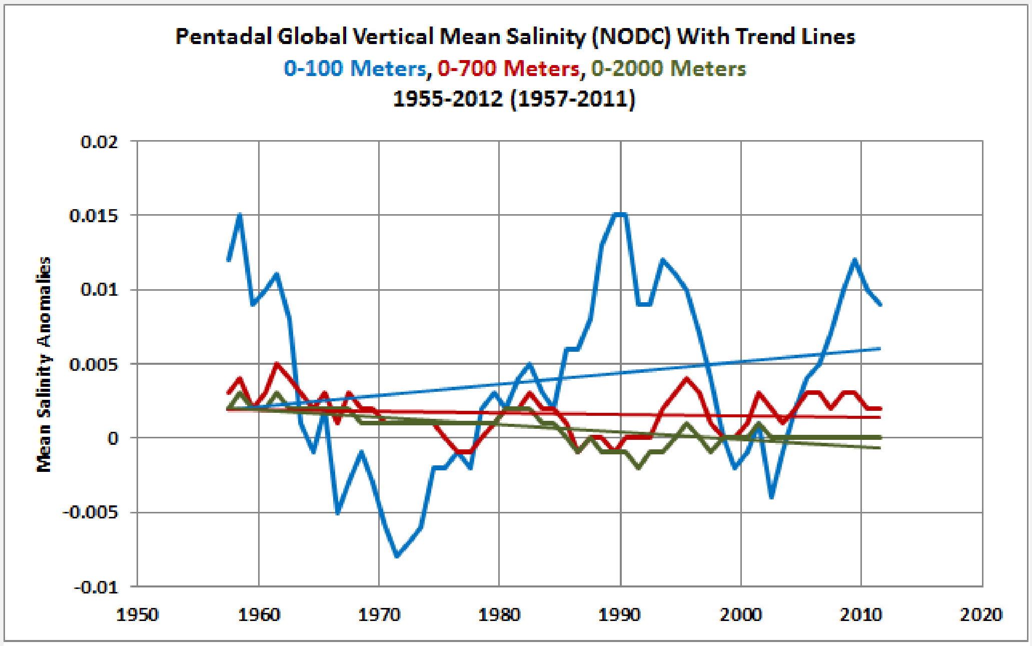


Figure 1.14-3

Figure 1.14-3 presents the NODC salinity data for the depths of 0-100 meters (0-328 feet), 0-700 meters (0-2300 feet), and 0-2000 meters (0-6560 feet), for the period of 1955 to 2013, on a pentadal basis. As a further explanation of the pentads, the first data points at 1957 presents the salinity anomalies for the period of 1955 to 1959, and the second data points at 1958 covers the period of 1956 to 1960, etc., through the last salinity data points at 2011 for the period of 2009 to 2013. As shown, the greatest variations in salinity take place in the top 100 meters (328 feet). The salinity data for the depths of 0-100 meters (0-328 feet) show an increase in salinity, while the two deeper subsets show slight decreases. And, according to the NODC salinity data, there are multidecadal variations in the salinity of top 100 meters of the global oceans.

Curiously, as soon as the ARGO floats were deployed, the salinity for the depths of 0-2000 meters (0-6560 feet) show no change. That is, the anomalies for the deepest dataset are zero for the pentads centered on 2002 through 2011.

OCEAN HEAT CONTENT DATA

The NODC then takes the temperature and salinity data and creates ocean heat content datasets for the depths of 0-700 meters (0-2300 feet) and 0-2000 meters (0-6560 feet). The ocean heat content data for the depths of 0-700 meters (0-2300 feet) are available from 1955 to present in quarterly, annual and pentadal formats. The NODC, on the other hand, only presents their long-term (1955 to present) ocean heat content data for the depths of 0-2000 meters (0-6560 feet) in pentadal form. They do, however, present the ARGO-era data (starting in 2005) for the depths of 0-2000 meters (0-6560 feet) in quarterly and annual formats. Once again, the NODC's ocean heat content data are supported by the Levitus et al. (2012) paper World ocean heat content and thermosteric sea level change (0–2000 m), 1955–2010.

Figure 1.14-4 compares the annual NODC global ocean heat content data for the depths of 0-700 meters (0-2300 feet) with their pentadal data for 0-2000 meters (0-6560 feet). Both depths show that the heat content of the oceans has increased since the mid-1950s.

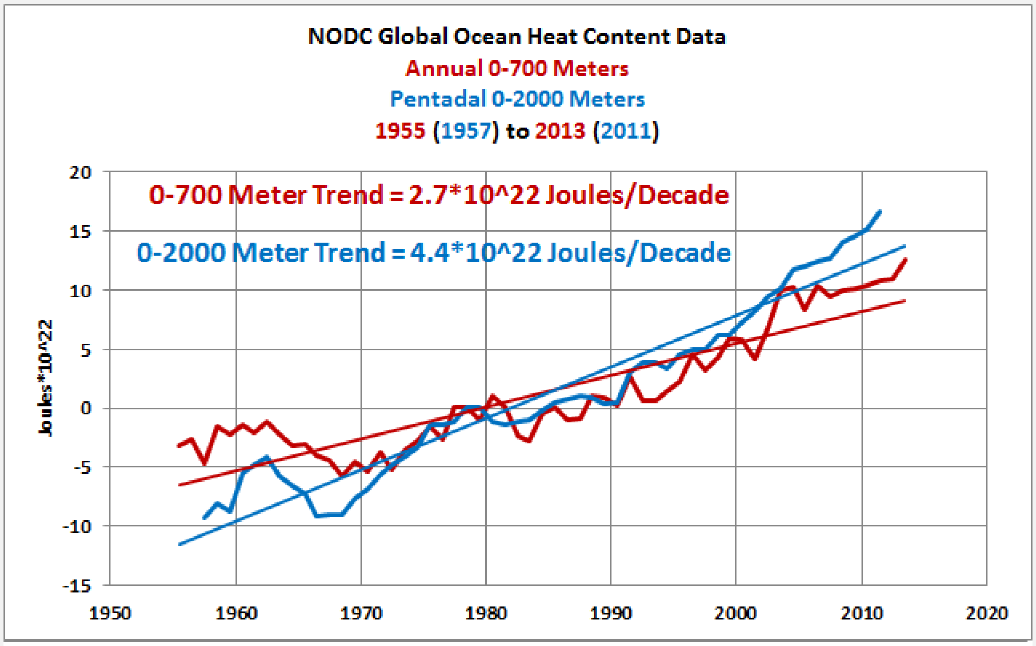


Figure 1.14-4

Note the units used by the climate science community for ocean heat content data are Joules*10^22 (read Joules times ten to the 22nd power). That's very impressive until we recall that the top 700 meters of the oceans warmed about 0.16 deg C (about 0.29 deg F) from 1955 to 2013, based on the linear trends, and for the top 2000 meters (about 6560 feet) the warming was less than 0.08 deg C (about 0.14 deg F) over that time period.

It also does not look very impressive if we present that as Heat Storage in watts/m^2 (read watts per square meter). In Table S1 of the Levitus et al. (2012) paper World ocean heat content and thermosteric sea level change (0–2000 m), 1955–2010, they indicate the increase in heat storage from 1955 to 2010 (based on linear trends) for the depths of 0-2000 meters (0-6560 feet) was about 0.39 watts/m^2. And in their Table S2, the NODC notes that the heat storage for the global oceans from 1955 to 2010 for the depths of 0-700 meters (0-2300 feet) was about 0.27 watts/m^2.

We'll discuss how those values relate to the energy imbalance later in this book, and you'll understand a really big flaw in the hypothesis of human-induced global warming…missing heat. That is, climate models say the oceans are supposed to have accumulated "x" amount of heat, but the data show much less heat accumulation...much less.

WHAT THE IPCC HAS TO SAY ABOUT OCEAN HEAT CONTENT DATA

The Technical Summary of the IPCC's 5th Assessment Report discusses the uncertainties with ocean heat content data. The following bullet points are found under the heading of "TS.6.1 Key Uncertainties in Observation of Changes in the Climate System" on page 114 (82 of 84):

- *Different global estimates of sub-surface ocean temperatures have variations at different times and for different periods, suggesting that sub-decadal variability in the temperature and upper heat content (0 to to 700 m) is still poorly characterized in the historical record. {3.2}*

These differences suggest it is difficult to isolate the cause of the warming of the oceans to depths of 700 meters because the different datasets show "variations at different times and for different periods". In other words, the different estimates in how, when and where the oceans warm and cool to depth make the data useless for attribution studies. That is, we might be able to link a change in subsurface ocean temperatures to a coupled ocean-atmosphere weather event using dataset "A", but suppose datasets "B" and "C" do not show the same shift at the same time at the same location. Then our attribution study is limited to one specific dataset, which makes our results questionable.

The IPCC continues:

- *Below ocean depths of 700 m the sampling in space and time is too sparse to produce annual global ocean temperature and heat content estimates prior to 2005. {3.2.4}*

Taking those two quotes together we can say that the data for the top 700 meters (2300 feet) is so "poorly characterized" among datasets that they cannot be used to attribute short-term variations, locally or globally, to mankind or nature, and if we have no understanding of the year-to-year variations, then we have no understanding of the decadal and multidecadal changes. Additionally, the data below 700 meters (to about 2000 meters, or 6560 feet) is so sparse before 2005 that they have no value when trying to attribute the warming to nature or mankind.

We'll be discussing ocean heat content and subsurface temperature data throughout this book.

1.15 – Can Infrared Radiation from Man-made Greenhouse Gases Warm the Oceans? – And Do the Data Indicate Something Other than Man-made Greenhouse Gases Caused that Warming?

There are numerous arguments about whether infrared radiation from anthropogenic greenhouse gases can warm the oceans. The answer to the title question is, yes, infrared radiation from man-made greenhouse gases can warm the oceans. Let's present a few of the arguments for and against.

A PARTLY FLAWED ARGUMENT

The first discussion is an argument with a seems-to-be-logical foundation: because infrared radiation can only penetrate the top few millimeters of the ocean surface, then it can't be the cause of ocean warming. Let me expand on that.

Due to the optical properties of ocean water, infrared radiation can only penetrate the top few millimeters of the ocean. Two millimeters equals 0.0787 inches or a little more than $^{1}/_{16}$ of an inch. On the other hand, sunlight can penetrate the oceans to depths of about 100 meters (330 feet), but most of the sunlight is absorbed in the top 10 meters (33 feet). See the Light Penetration in the Ocean webpage from San Jose University. So for the sake of discussion, let's use 2 millimeters for infrared radiation and 10 meters for solar radiation. The solar radiation (10 meters) penetrates 5000 times farther into the ocean than infrared radiation (2 millimeters or 0.002 meters).

It is also commonly known that infrared radiation has another factor working against it when it comes to its ability to heat the oceans: evaporation. The oceans can only release heat at the surface, and they release it primarily through evaporation. So if the infrared radiation can only penetrate the top few millimeters of the ocean surfaces, then much of the increase in infrared radiation from man-made greenhouse gases is quickly released to the atmosphere through evaporation. This, of course, limits the ability of infrared radiation to warm the oceans to depth.

However, what remains of the infrared signal (what has not been lost to evaporation) will cause the "skin" layer of oceans to rise in temperature, which limits the ability of the "bulk" ocean below the skin to release heat to the atmosphere.

Sunlight also has a factor working against it. The sun doesn't shine on the oceans at night.

The disparity between the abilities of sunlight and infrared radiation to heat the oceans has been known for decades. As a result, oceanographers have argued against man-made greenhouse gases having any measurable impact on ocean heat uptake. An example can be found in a 21st Century Science and Technology Magazine article. The article Yes, the Ocean Has Warmed; No, It's Not 'Global Warming' was written by the distinguished oceanographer Dr. Robert E. Stevenson. The Scripps Institute of Oceanography, UC San Diego wrote an obituary for Dr. Stevenson back in 2001. See Obituary Notice "Father of Space Oceanography" Robert E. Stevenson for an overview of Dr. Stevenson's achievements.

A portion of Dr. Stevenson's article *Yes, the Ocean Has Warmed; No, It's Not 'Global Warming'* reads (my boldface):

> ***How the Oceans Get Warm***
>
> *Warming the ocean is not a simple matter, not like heating a small glass of water. The first thing to remember is that the ocean is not warmed by the overlying air.*
>
> *Let's begin with radiant energy from two sources: sunlight, and infrared radiation, the latter emitted from the "greenhouse" gases (water vapor, carbon dioxide, methane, and various others) in the lower atmosphere. Sunlight penetrates the water surface readily, and directly heats the ocean up to a certain depth. Around 3 percent of the radiation from the Sun reaches a depth of about 100 meters.*
>
> *The top layer of the ocean to that depth warms up easily under sunlight. Below 100 meters, however, little radiant energy remains. The ocean becomes progressively darker and colder as the depth increases. (It is typical for the ocean temperature in Hawaii to be 26°C (78°F) at the surface, and 15°C (59°F) at a depth of 150 meters.*
>
> ***The infrared radiation penetrates but a few millimeters into the ocean. This means that the greenhouse radiation from the atmosphere affects only the top few millimeters of the ocean. Water just a few centimeters deep receives none of the direct effect of the infrared thermal energy from the atmosphere! Further, it is in those top few millimeters in which evaporation takes places. So whatever infrared energy may reach the ocean as a result of the greenhouse effect is soon dissipated.***
>
> *The concept proposed in some predictive models is that any anomalous heat in the mixed layer of the ocean (the upper 100 meters) might be lost to the deep ocean. There have been a number of studies in which this process has been addressed (Nakamura 1997; Tanimoto 1993; Trenberth 1994; Watanabi 1994; and White 1998). It is clear that solar-related variations in mixed-layer temperatures penetrate to between 80 to 160 meters, the average depth of the main pycnocline (density discontinuity) in the global ocean. Below these depths,*

> *temperature fluctuations become uncorrelated with solar signals, deeper penetration being restrained by the stratified barrier of the pycnocline.*
>
> *Consequently, anomalous heat associated with changing solar irradiance is stored in the upper 100 meters. The heat balance is maintained by heat loss to the atmosphere, not to the deep ocean.*

But that argument is flawed. We only have to return to the discussion in Chapter 1.9 – The Global Energy Budget and Figure 1.9-1 to see the flaw in that argument. The total downward shortwave and longwave radiation far exceed the amount of heat lost from the surface due to evaporation…even if we were to account for the differences in evaporative heat losses between land masses and oceans.

A FIELD EXPERIMENT HELPS TO SHOW THE IMPACT OF INFRARED RADIATION ON THE OCEANS

The climate science community also acknowledges the problems associated with infrared radiation and ocean heat uptake, and they performed field experiments to show that infrared radiation does warm the ocean surface. See the guest post Why greenhouse gases warm the oceans at RealClimate. RealClimate is a blog hosted by members of the climate science community. That guest post "Why greenhouse gases warm the oceans" was written by oceanographer Dr. Peter Minnett of the Rosensteil School of Marine and Atmospheric Science of the University of Miami. It serves as a common reference for global warming activists; see the SkepticalScience post How Increasing Carbon Dioxide Heats the Ocean. In his post at RealClimate, Dr. Minnett writes:

> *However, some have insisted that there is a paradox here – how can a forcing driven by longwave absorption and emission impact the ocean below since the infrared radiation does not penetrate more than a few micrometers into the ocean? Resolution of this conundrum is to be found in the recognition that the skin layer temperature gradient not only exists as a result of the ocean-atmosphere temperature difference, but also helps to control the ocean-atmosphere heat flux. (The 'skin layer' is the very thin – up to 1 mm – layer at the top of ocean that is in direct contact with the atmosphere). Reducing the size of the temperature gradient through the skin layer reduces the flux. Thus, if the absorption of the infrared emission from atmospheric greenhouse gases reduces the gradient through the skin layer, the flow of heat from the ocean beneath will be reduced, leaving more of the heat introduced into the bulk of the upper oceanic layer by the absorption of sunlight to remain there to increase water temperature. Experimental evidence for this mechanism can be seen in at-sea measurements of the ocean skin and bulk temperatures.*

<u>Change in Skin Temperature to Bulk Temperature Difference as a Function of the Net Longwave Radiation</u>

(From RealClimate Post "Why greenhouse gases warm the oceans" By Dr. Peter Minnett)

Total Depth of Measurements is Approximately 5 cm

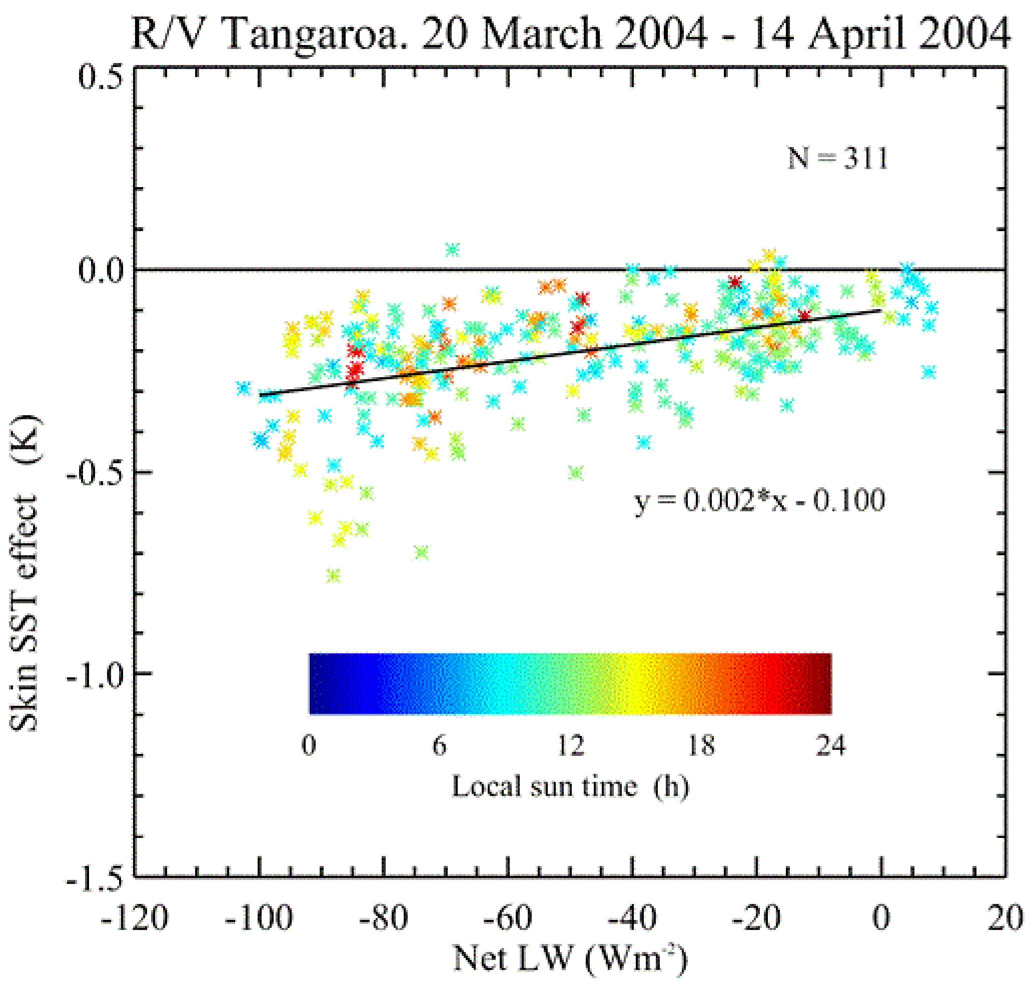


Figure 1.15-1

Dr. Minnett then goes on to describe the ocean cruise and techniques used for the at-sea measurements of the ocean skin and bulk temperatures. Figure 1.15-1 presents the results. It must be kept in mind that the depth for these temperature measurements of the ocean skin and bulk is only about 5 cm (about 2 inches). Dr. Minnett then adds with respect to his findings:

> *There is an associated reduction in the difference between the 5 cm and the skin temperatures. The slope of the relationship is 0.002ºK (W/m2)-1. Of course the*

> *range of net infrared forcing caused by changing cloud conditions (~100W/m2) is much greater than that caused by increasing levels of greenhouse gases (e.g. doubling pre-industrial CO_2 levels will increase the net forcing by ~4W/m2), but the objective of this exercise was to demonstrate a relationship.*

The results show a 0.002 deg C/watt/m^2 (that's 2 one-thousandths of a deg C per watt of additional downwelling longwave radiation per square meter) reduction in the difference between the depths of 5cm (2 inches) and the ocean skin as a function of longwave (infrared) radiation. It must be kept in mind that the 0.002 deg C/watt/m^2 figure is a reduction in the temperature gradient, not a change in the overall temperature of the surface. And as Dr. Minnett notes:

> *…if the absorption of the infrared emission from atmospheric greenhouse gases reduces the gradient through the skin layer, the flow of heat from the ocean beneath will be reduced, leaving more of the heat introduced into the bulk of the upper oceanic layer by the absorption of sunlight to remain there to increase water temperature.*

Dr. Minnett is saying that he has shown the increase in infrared radiation decreases the temperature difference between the depths of 5cm (2 inches) and the ocean skin, in turn showing that the flow of heat from the subsurface to the surface has been reduced with the increased infrared radiation. If the flow of heat from the subsurface to the surface has been decreased, then the oceans have to warm at depth.

So, once again, the answer is yes, the infrared radiation from greenhouse gases can and do warm the oceans.

As we discussed in Chapter 1.12, climate modelers assume all of the surface warming and ocean warming to the depths of the oceans were caused by the infrared radiation from anthropogenic greenhouse gases.

And, of course, downwelling longwave radiation at the surface has increase during the satellite era as shown in Figure 1.15-2, which includes the output of the NCEP-DOE Reanalysis 2. Again, a reanalysis is the output of a computer model that uses data as inputs. You'll note how the variations in the downwelling longwave radiation at the surface mimic the change in surface temperatures.

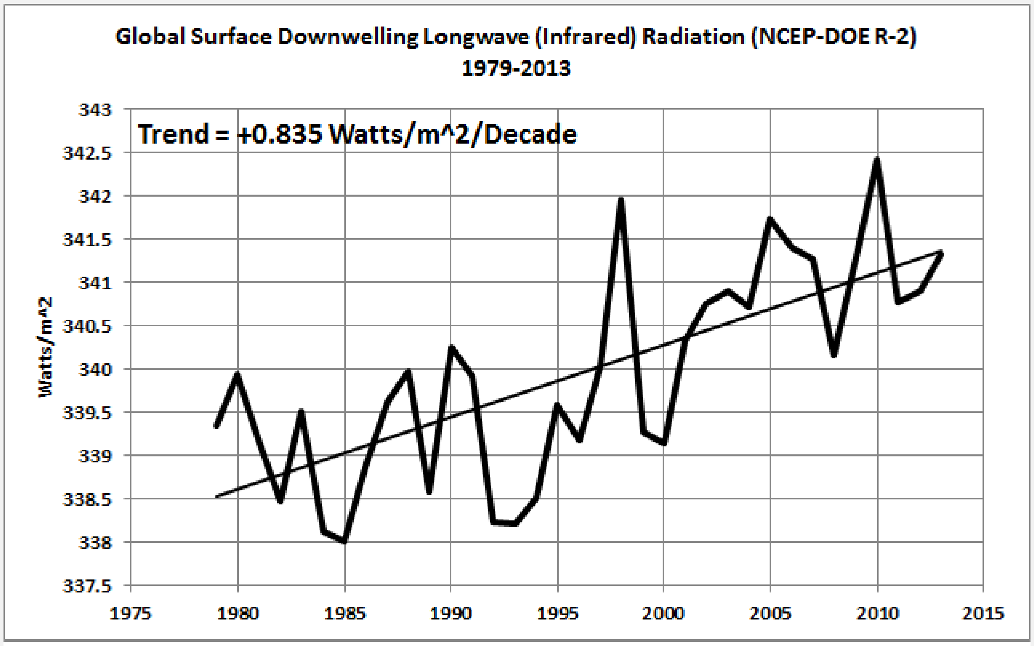


Figure 1.15-2

WHAT ABOUT SUNLIGHT?

And as we've discussed a few times already in this book, satellite observations of total solar irradiance at the top of the atmosphere provide the primary argument that sunlight is not the cause of ocean warming, either at the surface or at depth. Why? Because the measured total solar irradiance at the top of the atmosphere has decreased since 1979.

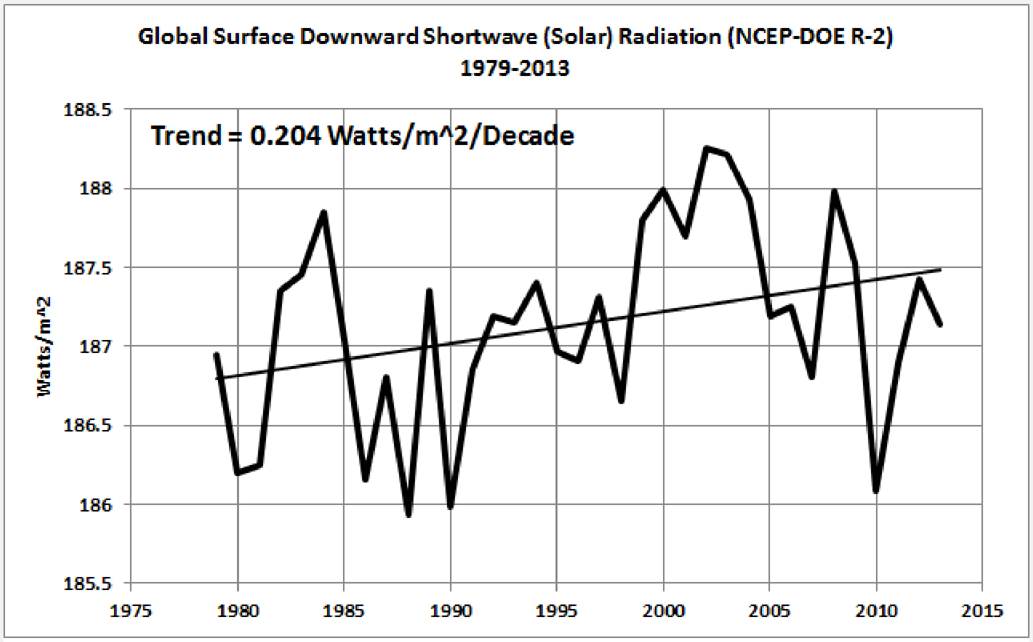


Figure 1.15-3

But we should be interested in how much sunlight is reaching the ocean surface, not what exists at the top of the atmosphere. There is evidence the amount of sunlight reaching the Earth's surface has also increased from 1979 to 2013. That metric is known as downward shortwave radiation (DSR) at the surface. Again we'll refer to the NCEP-DOE Reanalysis-2, and plot their calculated values for the downward shortwave (solar) radiation at the surface. See Figure 1.15-3 above.

The trend in downward longwave (infrared) radiation as shown in Figure 1.15-2 was more than 4 times higher than the trend of the downward shortwave radiation (sunlight) as shown in Figure 1.15-3. But as we discussed earlier in this chapter, sunlight can penetrate thousands of times deeper into the oceans than infrared radiation. Due to the differences in their abilities to penetrate to the depths of the oceans, the impacts of increases in sunlight (downward shortwave radiation) reaching the ocean surface will be many times greater than the impacts of increases in infrared radiation (downwelling longwave radiation).

We'll return to this topic a number of times throughout this book.

You may be looking at the graph in Figure 1.15-3 and noting that downward shortwave radiation at the surface increased until around 2002/03, but has been decreasing since then. That raises the question, why haven't the ocean surfaces or the oceans to depth cooled over the past 10 to 12 years? The logical answer is that the amount of sunlight reaching the ocean surface is still above the threshold that causes ocean heat uptake. The heat uptake simply would have slowed since 2002/03.

Another thing to consider: How much of the increase in downward longwave (infrared) radiation was actually caused by man-made greenhouse gases and how much of that increase results from the warming of Earth's surface, which may or may not be caused by man-made greenhouse gases, as discussed throughout this book? According to the NOAA Annual Greenhouse Gas Index, the total radiative forcing attributable to man-made greenhouse gases increased from 1.7 watts/meter^2 in 1979 to 2.9 watts/meter^2 in 2013, or a rise in infrared radiation of 1.2 watts/meter^2 from 1979 to 2013. But the total increase based on the linear trend shown in Figure 1.15-2 is about 2.9 watts/m^2, about 2.4 times the amount attributable to man-made greenhouse gases alone. Again, assuming there has been an increase in sunlight reaching Earth's surface as shown in Figure 1.15-3, due to the differences in their abilities to penetrate to the depths of the oceans, the impacts of increases in sunlight (downward shortwave radiation) reaching the ocean surfaces have to be many times greater than the impacts of increases in infrared radiation (downwelling longwave radiation).

THERE ARE NATURALLY OCCURRING PROCESSES THAT CAN CAUSE THE LONG-TERM WARMING OF THE OCEANS TO DEPTH

We've discussed above how infrared radiation from man-made greenhouse gases can in theory warm the oceans to depth. And based on a reanalysis, we've shown that sunlight reaching Earth's surface has also increased since the late 1970s, which would also explain the ocean heat uptake seen since then.

But we can also look to the data and see if it can tell us how, when and where it has warmed and why. For 5 to 6 years, I have been presenting the tale of the ocean heat content data and the naturally occurring processes that can cause long-term ocean heat uptake to depth.

The naturally occurring processes that can warm the oceans, of course, are not considered in the climate models used by the IPCC. Climate modelers' force the warming of the oceans based on their assumptions of how the infrared radiation from man-made greenhouse gases warm the oceans.

We're going to break the oceans down into ocean-basin subsets, because, for two of the subsets, climate scientists addressed those portions of the oceans in studies.

I've presented these discussions in previous posts and books using ocean heat content data. For a change of pace, I'm presenting the NODC depth-averaged temperature data for the depths of 0-700 meters.

TALE OF THE DATA: THE WARMING OF THE NORTH ATLANTIC TO DEPTH

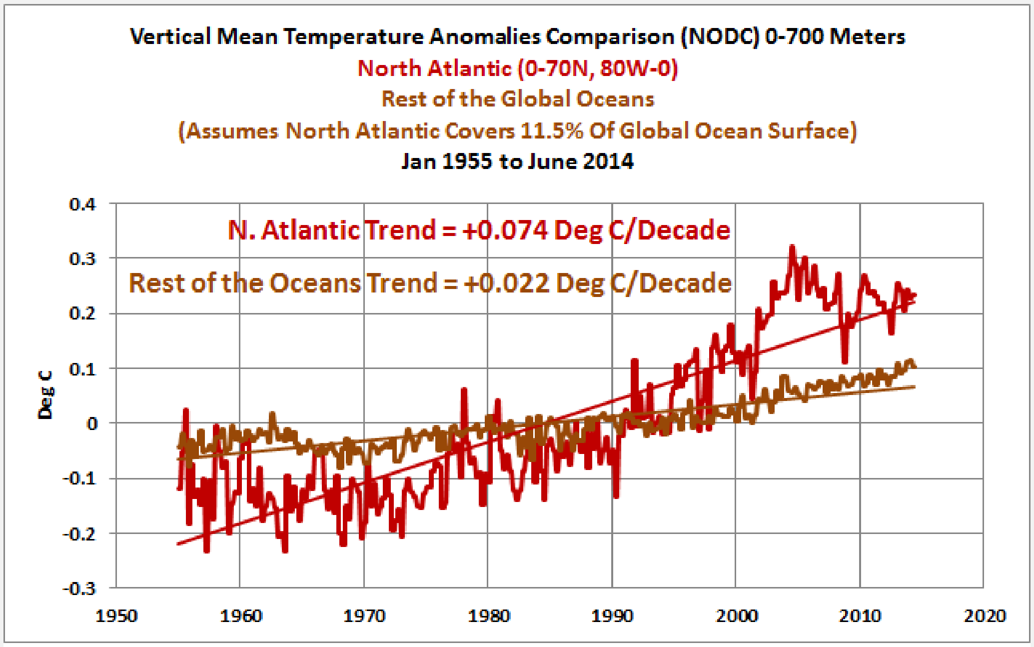


Figure 1.15-4

As a preface to our first discussion, Figure 1.15-4 presents the depth-averaged temperature anomalies (0-700 meters) for the North Atlantic and for the rest of the global oceans. To determine the depth-averaged temperature anomalies for the rest of the global oceans, I area-weighted the North Atlantic data (11.5%, see the NOAA webpage here) and subtracted it from the global data. The units are deg C.

It very obvious that the North Atlantic to depths of 700 meters warmed at a much faster rate than the rest of the oceans, about 3.3 times faster from 1955 to present. That ocean basin only covers 11.5% of the surface of the global oceans, yet it represents about 35% of the ocean warming to depths of 700 meters. Now consider that all the warming of the North Atlantic is considered in one climate study to have occurred naturally, not from man-made greenhouse gases as assumed by modelers. Using global ocean heat content as a proxy for radiative imbalance caused by man-made greenhouse gases is then obviously flawed.

NOTE: It is unfortunate that the outputs of the climate model simulations of depth averaged temperature (or ocean heat content) are not available in an easy-to-use form so that the models can be compared to observations. We know climate models do not properly simulate the warming of ocean surfaces. They double the warming rate of the ocean surfaces over the past 33 years. See the model-data comparison graph here. Also see the posts here and here for additional discussions. It would be interesting to see how poorly the models simulate ocean warming to depth. [End note.]

It's very obvious why the change in the ocean heat content is very important to the hypothesis of human-induced global warming. If the oceans could be shown to have warmed naturally, then the impacts of man-made greenhouse gases are much smaller than claimed by climate scientists.

And that's exactly what a group of scientists did back in 2008. They determined the warming of the North Atlantic to 700 meters since 1955 was caused by naturally occurring processes, not by man-made greenhouse gases. We've discussed this paper a few times in recent years—in blog posts and in books. Here's a portion of my ebook *Who Turned on the Heat?* I've updated it for this text.

[START OF REPRINT FROM *WHO TURNED ON THE HEAT?*]

There is a study that provides an explanation for that additional warming. See Lozier et al (2008) The Spatial Pattern and Mechanisms of Heat-Content Change in the North Atlantic.

First, a quick introduction to one of the terms used in the following quotes: The North Atlantic Oscillation is an atmospheric climate phenomenon in the North Atlantic. We'll discuss it in more detail in 3.10 – Atmospheric Mode – North Atlantic Oscillation (NAO).

The North Atlantic Oscillation is expressed as the sea level pressure difference between two points. The sea level pressures in Iceland, at the weather stations in Stykkisholmur or Reykjavik, can be used to calculate North Atlantic Oscillation Indices. Which Iceland location they elect to use as the high-latitude sea level pressure reference depends on the dataset supplier. The other point captures the sea level pressure at the mid-latitudes of the North Atlantic, and there are a number of locations that have been used for it: Lisbon, Portugal; Ponta Delgada, Azores; and Gibraltar. The North Atlantic Oscillation Index is primarily used for weather prediction. The direction and strength of the westerly winds in the North Atlantic are impacted by the sea level pressures in Iceland and the mid-latitudes of the North Atlantic, which, in turn, impact weather patterns in Europe and the East Coast of North America. If you live in those locations, you'll often hear your weather person referring to the North Atlantic Oscillation. As will be discussed, winds in the North Atlantic can also impact Ocean Heat Content.

I'll present two quotes from the Lozier et al (2008) paper. I'll follow them with quotes from the press release that describes in layman terms how the North Atlantic Oscillation impacts the Ocean Heat Content of the North Atlantic. Back to Lozier et al (2008):

The abstract reads:

> *The total heat gained by the North Atlantic Ocean over the past 50 years is equivalent to a basinwide increase in the flux of heat across the ocean surface of 0.4 ± 0.05 watts per square meter. We show, however, that this basin has not warmed uniformly: Although the tropics and subtropics have warmed, the subpolar ocean has cooled. These regional differences require local surface heat flux changes (±4 watts per square meter) much larger than the basinwide average. Model investigations show that these regional differences can be explained by large-scale, decadal variability in wind and buoyancy forcing as measured by the North Atlantic Oscillation index. Whether the overall heat gain is due to anthropogenic warming is difficult to confirm because strong natural variability in this ocean basin is potentially masking such input at the present time.*

In the paper, Lozier et al (2008) note, using NAO for North Atlantic Oscillation:

> *A comparison of the zonally integrated heat-content changes as a function of latitude (Fig. 4B) confirms that the NAO difference can largely account for the observed gyre specific heat-content changes over the past 50 years, although there are some notable differences in the latitudinal band from 35° to 45°N. Thus, we suggest that the large-scale, decadal changes in wind and buoyancy forcing associated with the NAO is primarily responsible for the ocean heat-content changes in the North Atlantic over the past 50 years.*

Based on the wording of the two quotes, the paper appears to indicate that Lozier et al (2008) are describing the entire warming of ocean heat content in the North Atlantic. In other words, it seems that Lozier et al (2008) are not stating that the North Atlantic Oscillation is primarily responsible for the additional ocean heat-content changes in the North Atlantic, above and beyond the rest of the world, over the past 50 years; they're saying it's primarily responsible for all of the increase. The press release for the paper, on the other hand, leads you to believe the North Atlantic Oscillation is responsible for the North Atlantic warming above and beyond the global warming.

The Duke University press release for the paper is titled North Atlantic Warming Tied to Natural Variability. Though the other ocean basins weren't studied by Lozier et al, the subtitle of the press release includes the obligatory reference to an assumed man-made warming in other basins: "But global warming may be at play elsewhere in the world's oceans, scientists surmise". To contradict that, we've found no evidence of an anthropogenic component in the warming of other ocean basins, as will be discussed in a few moments.

The press release reads with respect to the North Atlantic Oscillation (NAO):

> *Winds that power the NAO are driven by atmospheric pressure differences between areas around Iceland and the Azores. "The winds have a tremendous impact on the underlying ocean," said Susan Lozier, a professor of physical oceanography at Duke's Nicholas School of the Environment and Earth Sciences who is the study's first author.*

Further to this, they write:

> *Her group's analysis showed that water in the sub-polar ocean—roughly between 45 degrees North latitude and the Arctic Circle—became cooler as the water directly exchanged heat with the air above it.*
>
> *By contrast, NAO-driven winds served to "pile up" sun-warmed waters in parts of the subtropical and tropical North Atlantic south of 45 degrees, Lozier said. That retained and distributed heat at the surface while pushing underlying cooler water further down.*
>
> *The group's computer model predicted warmer sea surfaces in the tropics and subtropics and colder readings within the sub-polar zone whenever the NAO is in an elevated state of activity. Such a high NAO has been the case during the years 1980 to 2000, the scientists reported.*

> *"We suggest that the large-scale, decadal changes...associated with the NAO are primarily responsible for the ocean heat content changes in the North Atlantic over the past 50 years," the authors concluded.*

[END OF REPRINT FROM *WHO TURNED ON THE HEAT?*]

WHAT CAUSES THE WATER TO "PILE UP", INCREASING OCEAN HEAT CONTENT?

Let's discuss in more detail that "pile up" from the press release of Lozier et al. (2008). First, a few basics, which we'll discuss in more detail in Section 3: The trade winds are responses to the temperature difference between the equator and higher latitudes and to the rotation of the Earth. The warmer water near the equator causes warm air to rise there (convection). At the surface, winds blow from the mid latitudes toward the equator to make up for the deficit caused by the rising air, but the rotation of the Earth deflects that inrushing air to the west. Thus the trade winds blow from the northeast to the southwest in the Northern Hemisphere and from the southeast to the northwest in the Southern Hemisphere.

In the ocean basins, ocean circulation is driven primarily from the trade winds in the tropics blowing from east to west. That is, the trade winds push the surface waters from east to west in the tropics. Those westward-traveling waters warm under the tropical sun. They encounter a continental land mass and are directed toward the poles. In the North Atlantic, the western boundary current is known as the Gulf Stream. It carries the warm tropical waters to the cooler high latitudes, where that water can release heat to the atmosphere more efficiently. At the mid-latitudes, those waters encounter the west to east winds known as westerlies and are blown eastward toward Europe and Africa. The eastern boundary current along Africa returns those cooler waters back toward the tropics, where they can be warmed again, completing the cycle. That ocean circulation loop is called a gyre.

Now for the "piling up": Suppose the westerlies in the mid-latitudes slowed or reversed, while, at the same time, the trade winds were pushing the same amount of tropical water to the west and poleward. At mid-latitudes, the change in the strength or direction of the westerlies would resist the poleward transport of warm water from the tropics. That warm water would accumulate as a result. Here's that quote from the press release again:

> *By contrast, NAO-driven winds served to "pile up" sun-warmed waters in parts of the subtropical and tropical North Atlantic south of 45 degrees, Lozier said. That retained and distributed heat at the surface while pushing underlying cooler water further down*.

Presto. A naturally caused accumulation of heat in the North Atlantic.

Curiously, under the heading of "Beam Me Up, Scotty", Stefan Rahmstorf of Potsdam University and founding member of the blog RealClimate presented a similar discussion in his post What ocean heating reveals about global warming. I, of course, commented on that in my post Comments on Stefan Rahmstorf's Post at RealClimate "What ocean heating reveals about global warming"

Another example of how the North Atlantic can warm to depth over a multidecadal time period: Now suppose there were a series of strong El Niño events over a multidecadal period (1976 to the turn of the century for example), so that the tropical waters in the North Atlantic were naturally warmer than normal. Trenberth and Fasullo (2011) explain why some portions of the oceans remote to the tropical Pacific warm in response to an El Niño (my boldface):

> *But a major challenge is to be able to track the energy associated with such variations more thoroughly: Where did the heat for the 2009–2010 El Niño actually come from? Where did the heat suddenly disappear to during the La Niña? Past experience (Trenberth et al. 2002) suggests that global surface temperature rises at the end of and lagging El Niño, as heat comes out of the Pacific Ocean mainly in the form of moisture that is evaporated and which subsequently rains out, releasing the latent energy. Meanwhile,* ***maximum warming of the Indian and Atlantic Oceans occurs about 5 months after the El Niño owing to sunny skies and lighter winds (less evaporative cooling), while the convective action is in the Pacific****.*

That additional sunlight during a period when El Niños dominated (1976 to the turn of the century) would add to the amount of accumulating warm water in the North Atlantic…and elsewhere.

TALE OF THE DATA: EXTRATROPICAL NORTH PACIFIC

The next paper to be discussed is Trenberth and Hurrell (1994): Decadal Atmosphere-Ocean Variations in the Pacific. In it, Trenberth and Hurrell were using an index derived from the sea level pressures of the extratropical North Pacific (30N-65N, 160E-140W), called the North Pacific Index, to explain shifts in the sea surface temperatures of the North Pacific. Again, a sea level pressure index reflects changes in the wind patterns. My Figure 1.15-5 is Figure 6 from Trenberth and Hurrell (1994). We'll discuss the North Pacific Index in more detail in Chapter 3.11 – Atmospheric Mode - North Pacific Index (NPI).

Figure 6 from Trenberth and Hurrell (1994) "Decadal Atmosphere-Ocean Variations in the Pacific Ocean"

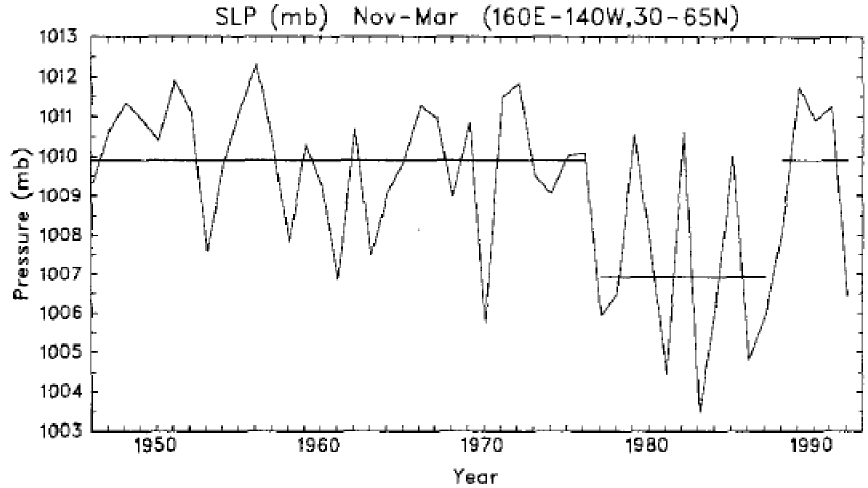


Fig. 6. Time series of mean north Pacific sea level pressures averaged over 30 to 65°N, 160°E to 140°W for the months November through March. Means for 1946–1976 plus 1989–1992 and 1977–1988 are indicated (where 1988 refers to the 1987–88 winter)

Figure 1.15-5

That same shift appears in the depth-averaged temperature data for the extratropical North Pacific (24N-65N, 120E-80W) for the depths of 0-700 meters. But the shifts are delayed a year in the subsurface temperature data. See Figure 1.15-6 below.

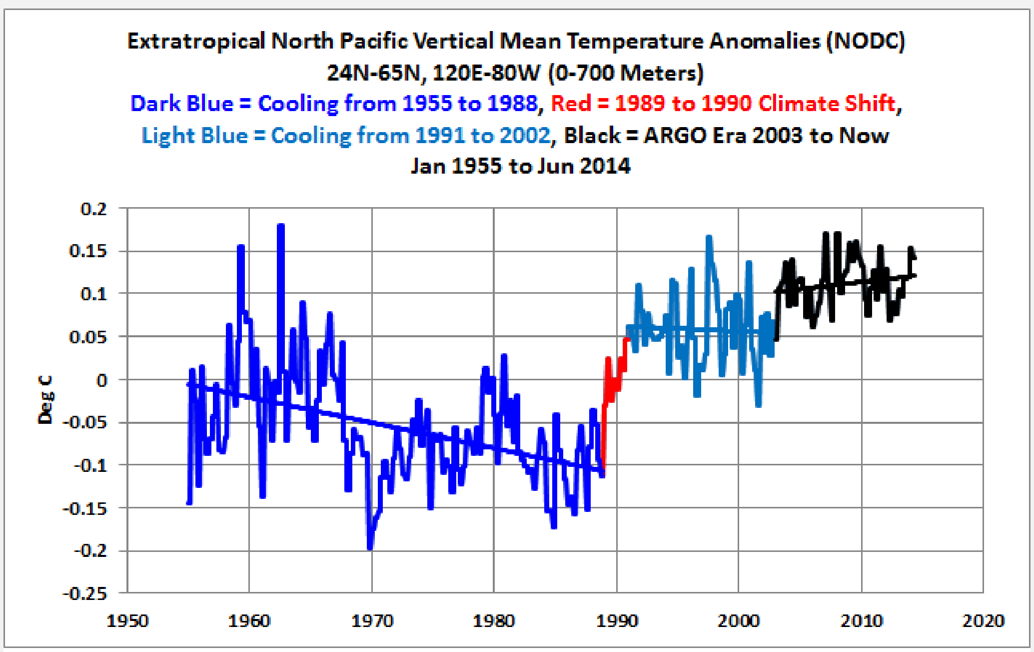


Figure 1.15-6

I've color-coded 4 periods on the graph in Figure 1.15-6. The first period from 1955 to 1988 (dark blue) includes the downward shift in 1978. As a result of that shift in 1978 (that should be related to the shift in the sea level pressures and wind patterns), the depth-averaged temperature data shows a cooling trend from 1955 to 1988. That is, the extratropical North Pacific to depths of 700 meters cooled (not warmed) for more than 3 decades, and all the while emissions of greenhouse gases were increasing. The second period (red) captures the upward shift in 1988 and 1989 that, once again, should be related to the shift in the sea level pressures and wind patterns. From 1991 to 2002 (light blue), the extratropical North Pacific cooled once again to depths of 700 meters. And since the ARGO floats were deployed (black), the extratropical Pacific shows a slight warming to depth.

It's blatantly obvious the extratropical North Pacific to depths of 700 meters would show no warming from 1955 to present if it wasn't for that upward shift in 1988 and 1989. It's also obvious that the downward shift in 1978 that extends to 1988 also impacts the long-term trend. That is, without the naturally caused downward shift in the late-1970s the long-term warming rate would be less. Obviously, natural variability, not man-made greenhouse gases, dominates the variability and long-term warming of the extratropical Pacific to the depths of 700 meters.

TALE OF THE DATA: TROPICAL PACIFIC

We isolate the vertically averaged temperature data to depths of 700 meters for the tropical Pacific because the tropical Pacific is where El Niño and La Niña events take place. (El Niño and La Niña events, collectively, are the dominant forms of natural variability on Earth.) A further clarification: while El Niño and La Niña events are focused on the equatorial Pacific, they directly impact the entire tropical Pacific. See the animation here for an extreme example of the effects of an El Niño on the sea level residuals of the tropical Pacific.

Let's start with two quotes from (again) Kevin Trenberth. According to Trenberth, El Niño events are fueled by sunlight, not man-made greenhouse gases. In the much-cited Trenberth et al. (2002) The evolution of ENSO and global atmospheric surface temperatures, they stated (my boldface and brackets):

> *The negative feedback between SST and surface fluxes can be interpreted as showing the importance of the **discharge** of heat during El Niño events and of the **recharge** of heat during La Niña events. Relatively clear skies in the central and eastern tropical Pacific [during a La Niña] allow **solar radiation** to enter the ocean, apparently offsetting the below normal SSTs, but the heat is carried away by Ekman drift, ocean currents, and adjustments through ocean Rossby and Kelvin waves, and the heat is stored in the western Pacific tropics. This is not*

> *simply a rearrangement of the ocean heat, but also a restoration of heat in the ocean. Similarly, during El Niño the loss of heat into the atmosphere, especially through evaporation, is a discharge of the heat content, and both contribute to the life cycle of ENSO.*

NOTE: That's the source of part of my standard description of ENSO as a chaotic, naturally occurring, sunlight-fueled, recharge-discharge oscillator…with El Niños acting as the discharge phase and La Niñas acting as the recharge phase. But La Niñas also help to redistribute the leftover warm waters from the El Niños. [End note.]

Also see Trenberth and Fasullo (2011). They confirm that ENSO is sunlight-fueled during La Niña events:

> *Typically prior to an El Niño, in La Niña conditions, the cold sea waters in the central and eastern tropical Pacific create high atmospheric pressure and clear skies, with plentiful sunshine heating the ocean waters. The ocean currents redistribute the ocean heat which builds up in the tropical western Pacific Warm Pool until an El Niño provides relief (Trenberth et al. 2002).*

Figure 1.15-7 presents the vertically averaged temperature anomalies (0-700 meters) for the tropical Pacific. El Niño and La Niña events directly impact the top 300 meters, so this depth captures those influences. I've highlighted in maroon the three 3-year La Niña events of 1954 to 1957, 1973 to 1976, and 1998 to 2001. After those 3-year La Niña events, the tropical Pacific shows cooling, not warming. That indicates that the shorter La Niñas (that happen between the three multiyear La Niñas) only recharge part of the warm water released from the tropical Pacific by the El Niños that precede them. Also, I've highlighted in red the 7-month period associated with the 1995/96 La Niña. (See the old version of the NOAA ONI index. Archived here.) The 1995/96 La Niña created the warm water that fueled the 1997/98 El Niño, which is responsible for the sharp drop in temperature following the heat uptake of the 1995/96 La Niña. The "overcharge" from the 1995/96 La Niña and the recharge during the 1998-01 La Niña obviously caused an upward shift in the subsurface temperatures of the tropical Pacific.

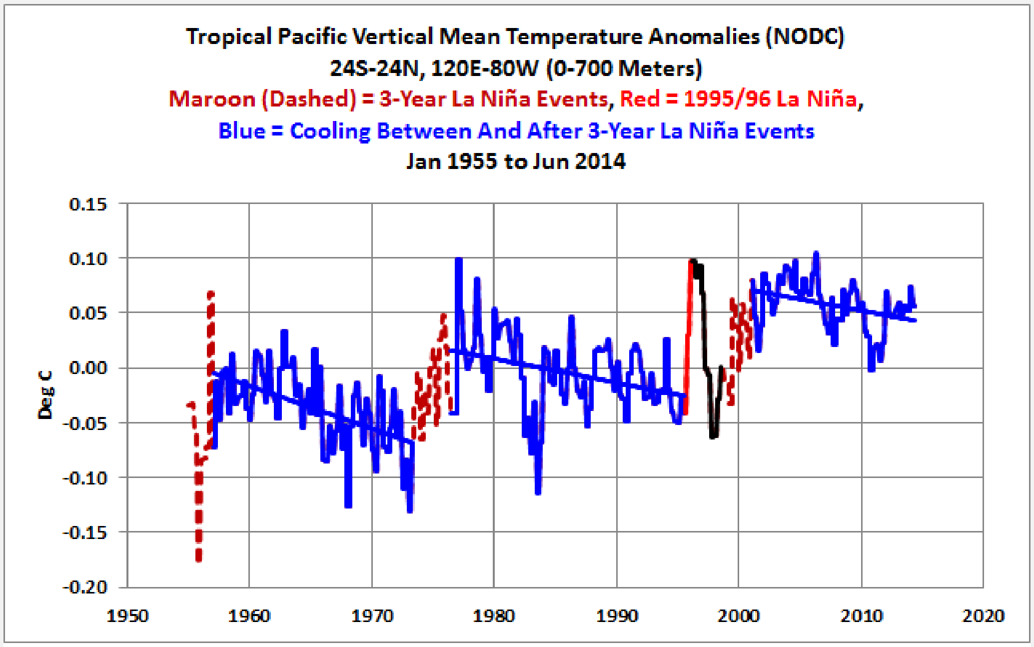


Figure 1.15-7

What is also blatantly obvious is the warming of the tropical Pacific to depth is dependent on 4 La Niña events. And according to Trenberth et al. (2002) and Trenberth and Fasullo (2011), sunlight warms the tropical Pacific during La Niñas, not infrared radiation from man-made greenhouse gases. (In the real world, downwelling longwave radiation (infrared radiation) decreases during La Niña events.)

BOTTOM LINE ON OCEAN TEMPERATURE DATA FOR THE DEPTHS OF 0-700 METERS

Subsurface temperature data (and ocean heat content data) for the North Atlantic, the Extratropical North Pacific and the Tropical Pacific all indicate that naturally occurring coupled ocean-atmosphere processes are the primary causes of ocean warming to depth, not man-made greenhouse gases. In fact, the data for the tropical Pacific and extratropical North Pacific show those oceans can cool for decadal and multidecadal periods between short-term naturally caused warming episodes. Those cooling episodes further suggest that man-made greenhouse gases have no measureable impact on ocean warming to depth.

Let me borrow a graph (Figure 26) from the post Is Ocean Heat Content Data All It's Stacked Up To Be? See Figure 1.15-8. It compares global ocean heat content in red to the combined Extratropical North Pacific and Tropical Pacific subsets (Figures 1.15-6 and 1.15-7), shown in blue.

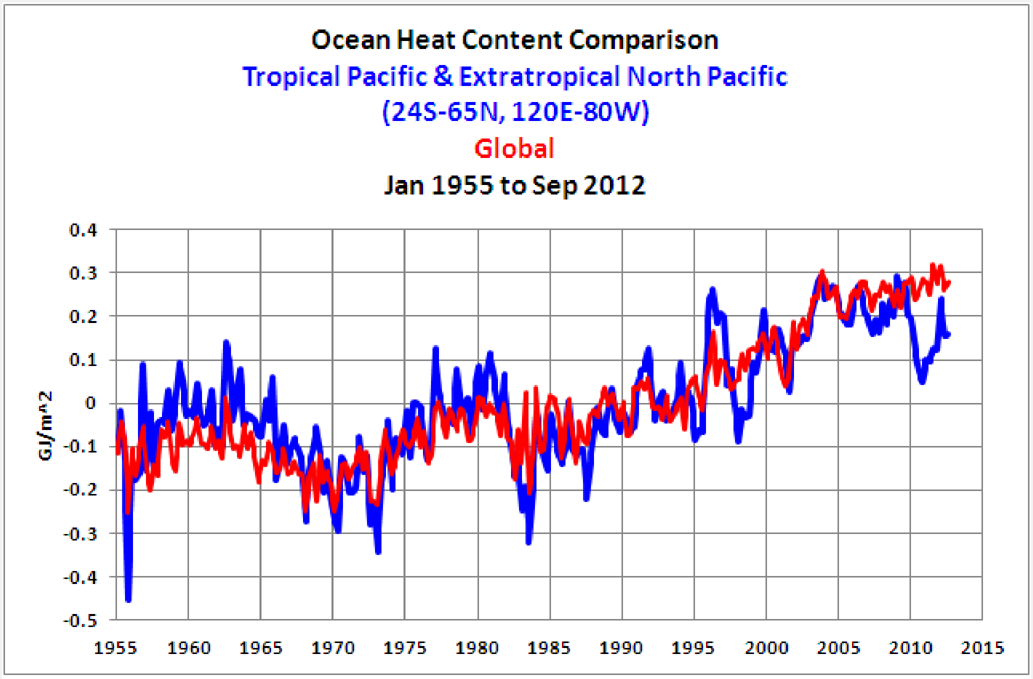


Figure 1.15-8

As discussed, the Tropical Pacific and Extratropical Pacific subsets individually show no evidence of having been warmed from man-made greenhouse gases, but when merged, the global ocean heat content data mimic the long-term warming and the short-term variations of the combination of the Tropical Pacific and Extratropical Pacific subsets. Now consider that the warming of the North Atlantic was also found to have occurred naturally.

FINAL NOTES FOR THIS CHAPTER

We discussed Radiative Imbalance in Chapter 1.11. There we referred to the paper Stephens et al, (2013) An update on Earth's energy balance in light of the latest global observations, who found the global radiative imbalance to be 0.6 watts/m^2. Referring to Figure 1.15-3 above, note how, based on the linear trend, the downward shortwave (solar) radiation reaching the surface increased about 0.7 watts/m^2 from 1979 to 2013.

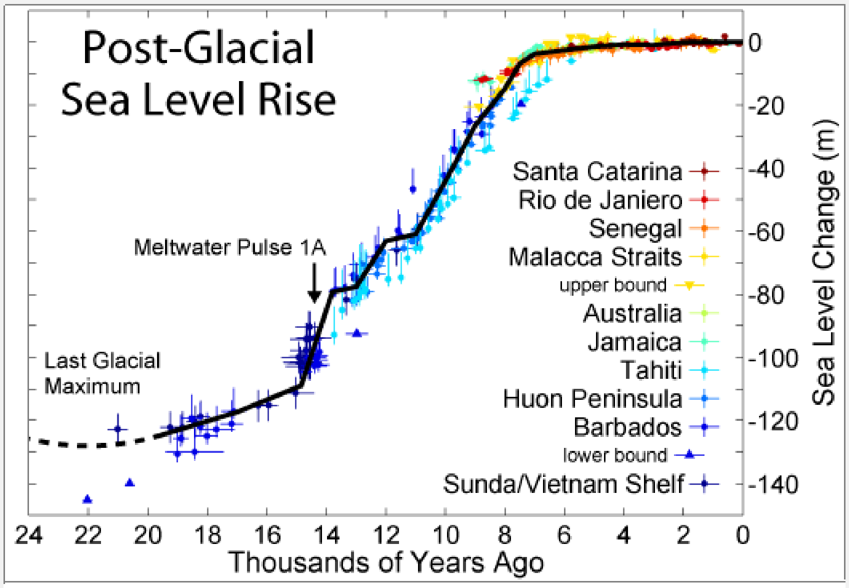
It's odd, to say the least, that the climate science community seems to ignore the possibility that an increase in sunlight could be responsible for the warming of the oceans…and for the resulting radiative imbalance.

It's also very odd that the climate science community continues to ignore the tales of the subsurface ocean temperature and ocean heat content data, which indicate that natural processes can explain the ocean heat uptake.

I presented many of the same arguments for and against infrared radiation warming the oceans in the post Arguments For and Against Human-Induced Ocean Warming. There are many more arguments for and against, however, in the comments of the cross post at WattsUpWithThat. The discussions there continued for weeks.

1.16 – Sea Levels Are Rising

For many people, especially persons living near the coasts, sea level is the critical metric associated with global warming and climate change. Paleoclimatological studies indicate the surface of the oceans were lowest at the peak of the last ice age (about 20,000 years ago). As the globe cooled during the last ice age, water from the oceans accumulated as snow in the high latitudes of the Northern Hemisphere, eventually turning to large land-based blocks of ice called glaciers. Sea levels dropped during the ice age, because the water for the growing ice sheets on land came from the oceans. Then the Earth began to warm again, and as the glaciers and ice sheets melted and the oceans warmed again, the global sea level rose in the neighborhood of 125 meters (410 feet). See Figure 1.16-1.



Source: Wikipedia http://en.wikipedia.org/wiki/File:Post-Glacial_Sea_Level.png

Figure 1.16-1

Traveling further back in time to the warming period between the last two ice ages—a period known as the last interglacial—sea levels were much higher than they are today. Let's look again at the Technical Summary of the IPCC's 5th Assessment Report. Under the heading of TS2.6 Changes in Sea Level, on page 46 (14 of 84), the IPCC writes (my brackets):

> *There is* very high confidence *that maximum GMSL* [global mean sea level] *during the last interglacial period (129 to 116 ka) was, for several thousand years, at least 5 m higher than present and* high confidence *that it did not exceed 10 m above present, implying substantial contributions from the Greenland and*

> *Antarctic ice sheets. This change in sea level occurred in the context of different orbital forcing and with high-latitude surface temperature, averaged over several thousand years, at least 2°C warmer than present (*high confidence*).*

In other words, global sea level was 5 to 10 meters (16 to 32 feet) higher during the last interglacial. But in order for sea levels to rise to those levels, global temperatures were much warmer than they are today (about 2 deg C) for several thousand years. Some might say it's not a matter of if sea levels will rise 5 to 10 meters (16 to 32 feet) during the current interglacial, it's when they will reach those levels.

Concern about sea level rise depends on location. Much of The Netherlands and the City of New Orleans are below present local sea levels, so rising sea levels are major concerns there. On the other hand, land surfaces are rising in other parts of the Northern Hemisphere—the result of a phenomenon called post-glacial rebound—and the rise in the land surfaces has outpaced the rise in local sea level. We'll discuss post-glacial rebound later in this chapter.

FACTORS CONTRIBUTING TO SEA LEVEL RISE IN RECENT YEARS

Table 1.16-1 IPCC AR5 Contributors to Sea Level Rise

	IPCC AR5 (1993-2010)	
Contributors to Sea Level Rise	mm/yr	%
Thermal expansion	1.1	37.4%
Glaciers and ice caps	0.76	25.9%
Glaciers in Greenland	0.1	3.4%
Greenland ice sheet	0.33	11.2%
Antarctic ice sheet	0.27	9.2%
Land water storage	0.38	12.9%
Sum	2.94	100%
Measured	3.2	

There are a number of factors that contribute to the rise in global sea level. The Summary for Policymakers of the 5th Assessment Report lists those factors. See their third bullet point under the heading of "B.4 Sea Level", on page 9 (15 of 33). They are:

- Thermal expansion
- Glaciers and ice caps
- Greenland ice sheet
- Antarctic ice sheet
- Land water storage

Their contributions are shown in Table 1.16-1 above and in the pie chart below in Figure 1.16-2. Thermal expansion is the greatest contributor.

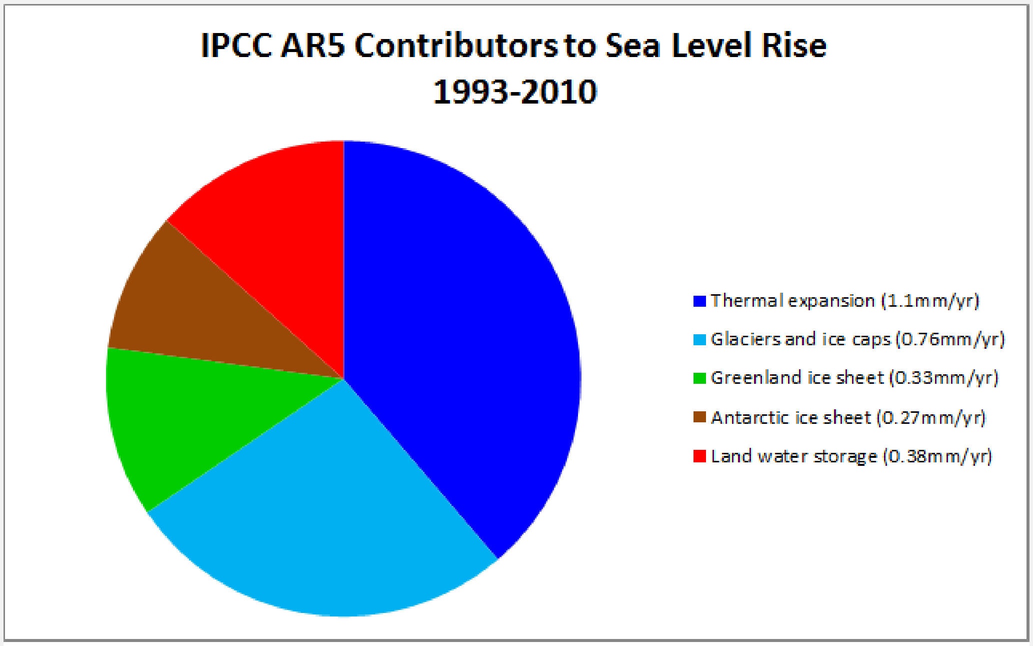


Figure 1.16-2

The rate of 3.2 mm/year (0.126 inches/year) indicates that global sea levels have risen 54.4 mm (a little more than 2 inches) during the 17 years from 1993 to 2010.

In Chapter 13 of AR5, the IPCC isolated (added) “Glaciers in Greenland”, adding another 0.1 mm/year to the budget, but that was not a major change in the total contribution from Glaciers and ice caps.

Logically, as the oceans warmed, they expanded; thus, the thermal expansion component. And because the temperatures at the glaciers, ice caps and the ice sheets are, seasonally, above the freezing point of water (and have been since the end of the last ice age), melting ice has contributed to the sea level rise.

The IPCC discussed land water storage in “Section 13.3.4 Contributions of water storage on land” of their 5th Assessment Report. The final paragraph of that section reads:

> *In summary, climate-related changes in water and snow storage on land do not show significant long-term trends for the recent decades. However, direct human interventions in land water storage (reservoir impoundment and groundwater depletion) have each contributed at least several tenths of mm yr^{-1} of sea level change (Figure 13.4, Table 13.1). Reservoir impoundment exceeded groundwater depletion for the majority of the 20th century but groundwater depletion has increased and now exceeds current rates of impoundment,*

contributing to an increased rate of GMSL rise. The net contribution for the 20th century is estimated by adding the average of the two groundwater depletion estimates to the reservoir storage term (Figure 13.4c). The trends are -0.11 [-0.16 to -0.06] mm yr^{-1} for 1901-1990, 0.12 [0.03 to 0.22] mm yr^{-1} for 1971 to 2010 and 0.38 [0.26 to 0.49] mm yr^{-1} for 1993 to 2010 (Table 13.1).

In other words, the damming of rivers reduced the rate of sea level rise for most of the 20th Century, until the 1970s, because the dams held back more water than we were pumping from below the ground. After the 1970s, ground water pumping exceeded the volume of water being held back by the dams, and the net contribution of changes in land water storage cause sea levels to rise 0.38 mm/year from 1993 to 2010. To put that in perspective, there are 25 millimeters to an inch, so 0.38 mm/year is a tiny amount.

IPCC MADE MAJOR CHANGES SINCE AR4

The IPCC has made a couple of major changes since their 4th Assessment Report. Table 1.16-2 is similar to Table 1.16-1 but it also includes the contributors to sea level rise from the IPCC's 4th Assessment Report (AR4). The values listed on Table 1.16-2 are from the IPCC's Table 5.3, which was included in their Section 5.5.6 Total Budget of the Global Mean Sea Level Change.

Table 1.16-2 IPCC AR4 & AR5 Contributors to Sea Level Rise

	IPCC AR4 (1993-2003)		IPCC AR5 (1993-2010)	
Contributors to Sea Level Rise	**mm/yr**	**%**	**mm/yr**	**%**
Thermal expansion	1.6	57.3%	1.1	37.4%
Glaciers and ice caps	0.77	27.6%	0.76	25.9%
Glaciers in Greenland			0.1	3.4%
Greenland ice sheet	0.21	7.5%	0.33	11.2%
Antarctic ice sheet	0.21	7.5%	0.27	9.2%
Land water storage			0.38	12.9%
Sum	2.79	100%	2.94	100%
Measured	3.1		3.2	

The noticeable changes from the 4th to 5th Assessment Reports are the additions of the contributions from the Glaciers in Greenland and from the Land water storage (groundwater pumping). They weren't considered in AR4, but a few years later in AR5 those two factors combined were then thought to have contributed more than 16% to the rise in sea level. From AR4 to AR5, the contributions from the Greenland and Antarctic ice sheets increased markedly. From one assessment report to the next, the Antarctic ice sheet contribution jumped from 0.21 to 0.27 mm/year or about 29% and the contribution from the Greenland ice sheet jumped from 0.21 to 0.33 mm/year or about 57%. All of those increases had to come from somewhere, and they came from the thermal expansion contribution. Instead of the increase in ocean heat contributing 1.6 mm/year to global sea level rise, the IPCC dropped that contribution to 1.1 mm/year. That's a drop in the contribution from ocean heating of about 31%.

And that leaves us with a very obvious question: where'd all of that ocean heat go?

Recall our discussions of the Total Energy Change Inventory in Chapter 1.14. Melting ice (including Arctic sea ice, ice sheets and glaciers) accounts for only 3% of the total energy change inventory, while ocean heating made up 93%. So there is no conceivable way to account for the 31% drop in ocean heat's contribution to sea level rise with a paltry 46% increase from melting ice.

Where did all of that ocean heat go?

A good portion of ocean heat used to drive rising sea levels in the 2007 IPCC report simply disappeared in their 2013 report. In other words, it never existed according to the ever-changing consensus (groupthink). Does that sound like climate science is settled?

A NEW STUDY SAYS ANTARCTICA ICE SHEETS ARE GAINING ICE MASS, NOT LOSING IT

A brand new study in 2015 by Zwally and others may upset those numbers again. The paper is Mass gains of the Antarctic ice sheet exceed losses. That is, instead of Antarctic ice sheets contributing to sea level rise, the Antarctic ice sheets have been gaining mass and suppressing the rise in global sea levels. For further information, see the October 30, 2015 NASA press release NASA study: Mass Gains of Antarctic Ice Sheet Greater than Losses.

[Sarcasm on.] But that doesn't appear to be a problem for the IPCC. They can just add it back to thermal expansion to make up for the loss of its contribution from the 4^{th} to the 5^{th} Assessment Reports. [Sarcasm off.] It'll be fun to see how they account for this in the 6^{th} Assessment Report.

TIDE GAUGES AND SATELLITE-BASED SEA LEVEL OBSERVATIONS

Tide gauges are devices that record the water level at a location. They can be used to establish whether the water levels are rising and falling by comparing them to a land reference called a benchmark. Logically, tide gauges are located along continental and island shorelines. Tide gauge data have been collected by the Permanent Service for Mean Sea Level (PSMSL) organization since the early 1930s, with some of their records extending much further back in time. There are many factors that have to be considered when determining mean sea level. See the PSMSL Frequently Asked Questions webpage for further information. We'll discuss a few of them later in this chapter.

Since the early 1990s, satellites have been used to measure the changes in sea level of the global oceans. That is, the satellite-based altimetry data provide a complete view of the changes in sea level, where with tide gauges only measured sea level along the coasts. The satellite-based sea level data are available from a number of sources, including:

- University of Colorado
- AVISO
- CSIRO
- NASA PODAAC
- NOAA

They all appear to rely on the same satellites, and they all appear to produce global sea level products with similar trends.

In addition to the Permanent Service for Mean Sea Level (PSMSL) webpage, tide gauge sea level data are available through the KNMI Climate Explorer here. They are coastal sea level data (globally) based on the Jevrejeva at al. (2006) paper Nonlinear trends and multiyear cycles in sea level records. (Preprint available here.)

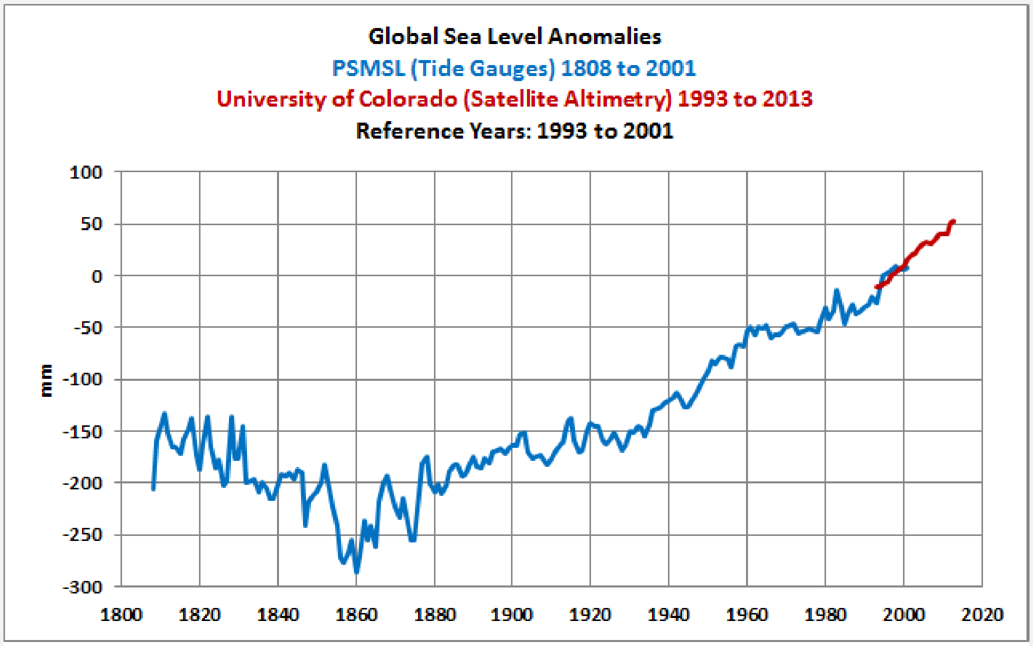


Figure 1.16-3

Figure 1.16-3 presents a time-series graph of the tide gauge-based global sea level data from 1807 to 2001, in blue. Also included in the graph (in maroon) are the satellite-based altimetry data from the University of Colorado for the period of 1993 to 2013 (2014 version release 1.) Both datasets have been converted to annual averages and referenced to the common period of 1993 to 2001 for anomalies. As shown, since the mid-1800s, global sea level has risen about 300mm or roughly 12 inches.

IS THE RISE IN SEA LEVEL ACCELERATING?

Alarmists have been known to compare tide gauge-based and satellite-based sea level data and claim that the rise in global sea level is accelerating. For example, Figure 1.16-4 compares the trends in mm/year for the global satellite-based sea level data with the global tide gauge-based data from 1855 to 2001. The trends are quite different. The satellite-era data have a trend of 3.2 mm/year (about 0.125 inches/year) while the long-term tide-gauge data have a trend of about 1.7 mm/year (about 0.067 inches/year). But there are two ways in which those comparisons can be misleading.

First, tide gauges measure sea levels along shorelines, while satellites measure sea levels of the global oceans. To add to the complexities, there are major differences in rates of sea level change (rising in some locations, falling in others) throughout the oceans and shorelines. Unless the satellite-based measurements are broken down and provided for the same coordinates as the tide gauges, comparisons like the one shown in Figure 1.16-4 are not accounting for those differences.

The second point to consider is that satellites are calibrated against tide gauges, so along the shorelines the trends of the raw satellite data should be similar to those of the tide gauges.

The third difference between the two datasets is that the satellite data receive additional adjustments to account for factors such as post-glacial rebound, which we'll discuss in more detail in a moment. Those adjustments may be important to scientific studies. But are they relevant to the problems many shoreline communities will encounter with rising sea levels? Sea levels are a local problem facing shoreline communities. They do not care about the sea levels out in the middle of the oceans.

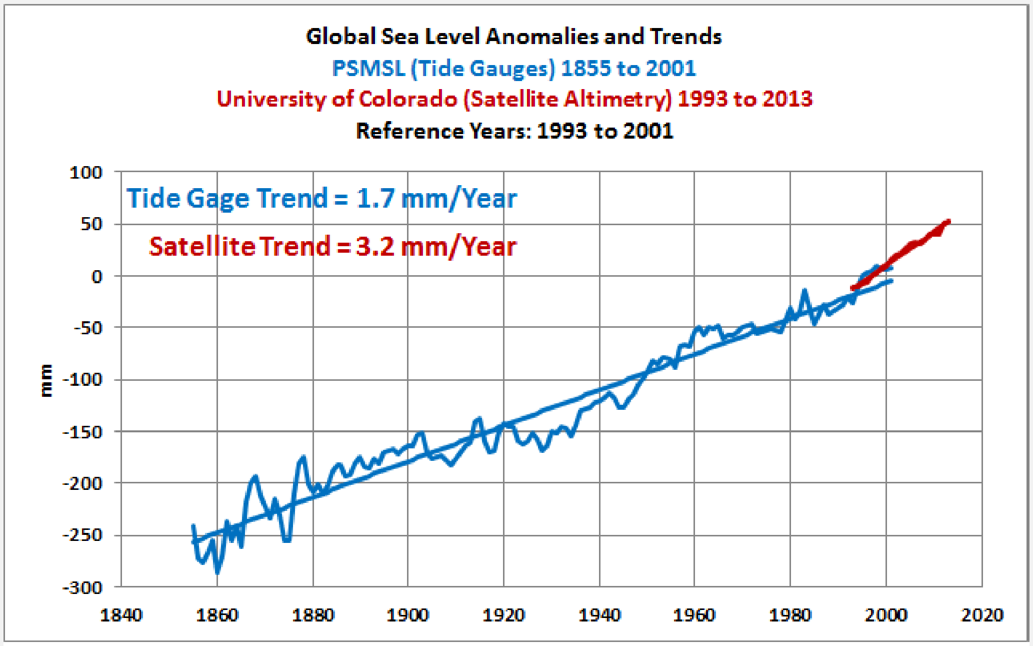


Figure 1.16-4

A fourth difference: it's very obvious in Figure 1.16-4 that the rise in sea level in the long-term tide gauge data has not been steady. The data modulate back and forth across the linear trend line. There appear to be multidecadal periods when the sea level rise accelerates and other multidecadal periods when the rise decelerates.

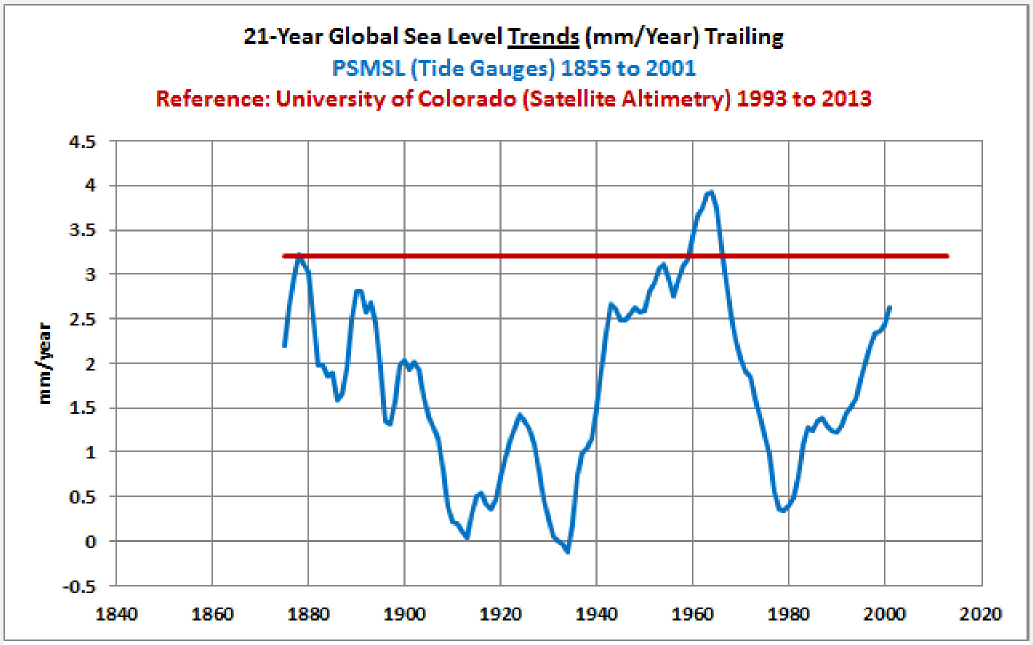


Figure 1.16-5

Satellite-based sea level data have been available for just over two decades and we know the trend for that dataset is about 3.2 mm/year. So we can use that as a reference. Let's determine the 21-year trends for the PSMSL global tide gauge data starting with the most recent 21-year period (1981-2001) and work our way back in time through the earliest period (1855-1875). See Figure 1.16-5.

The horizontal maroon line is the 21-year linear trend of the satellite-based global sea level data (3.2 mm/year) for the period of 1993-2013. The blue data point at 2001 is the 21-year trend of the PSMSL data for the period of 1981-2001. The blue data point immediately before it at 2000 is the trend for the period of 1980-2000, and before that at 1999 is the trend for 1979-1999, and so on, working our way back in time to the first 21-year period of 1855-1875. In other words, the blue curve is showing the 21-year trends of the long-term tide gauge data in 1-year increments, and the trend is shown at the last year of the 21-year period.

As shown, the 21-year period ending in 1878 had a trend that was comparable to the trend of the 21-year satellite-based data ending in 2013. And the 21-year rates of sea level rise ending in 1960 through 1967 were greater than the satellite-based data. In fact sea levels for the 21-year period ending in 1964 rose at a noticeably higher rate than was experienced during the satellite era of 1993-2013.

Further to topic of the rise of sea levels accelerating: There's a 5-year-old study of sea level data from the United States and around the globe. The title of Houston & Dean's (2010) study is Sea-Level Acceleration Based on U.S. Tide Gauges and Extensions of Previous Global-Gauge Analyses. The title would lead you to believe they found sea levels accelerating. But their conclusions indicate the opposite (My boldface.):

> *Our analyses do not indicate acceleration in sea level in U.S. tide gauge records during the 20th century. Instead, for each time period we consider, the records show small decelerations that are consistent with a number of earlier studies of worldwide-gauge records. The decelerations that we obtain are opposite in sign and one to two orders of magnitude less than the +0.07 to +0.28 mm/y^2 accelerations that are required to reach sea levels predicted for 2100 by Vermeer and Rahmsdorf (2009), Jevrejeva, Moore, and Grinsted (2010), and Grinsted, Moore, and Jevrejeva (2010). Bindoff et al. (2007) note an increase in worldwide temperature from 1906 to 2005 of 0.74°C.* ***It is essential that investigations continue to address why this worldwide-temperature increase has not produced acceleration of global sea level over the past 100 years, and indeed why global sea level has possibly decelerated for at least the last 80 years.***

SEA LEVEL TRENDS ARE NOT UNIFORM

The satellite-era trends also show that the rise in sea level around the global oceans is not uniform around the global oceans. The suppliers of altimetry-based sea level data produce trend maps that show this well. Figure 1.16-6 is an example from the AVISO website here. The highest trend in sea level rise is in the western tropical Pacific, east of the Philippines. Then again, sea levels have dropped in many parts of the eastern Pacific.

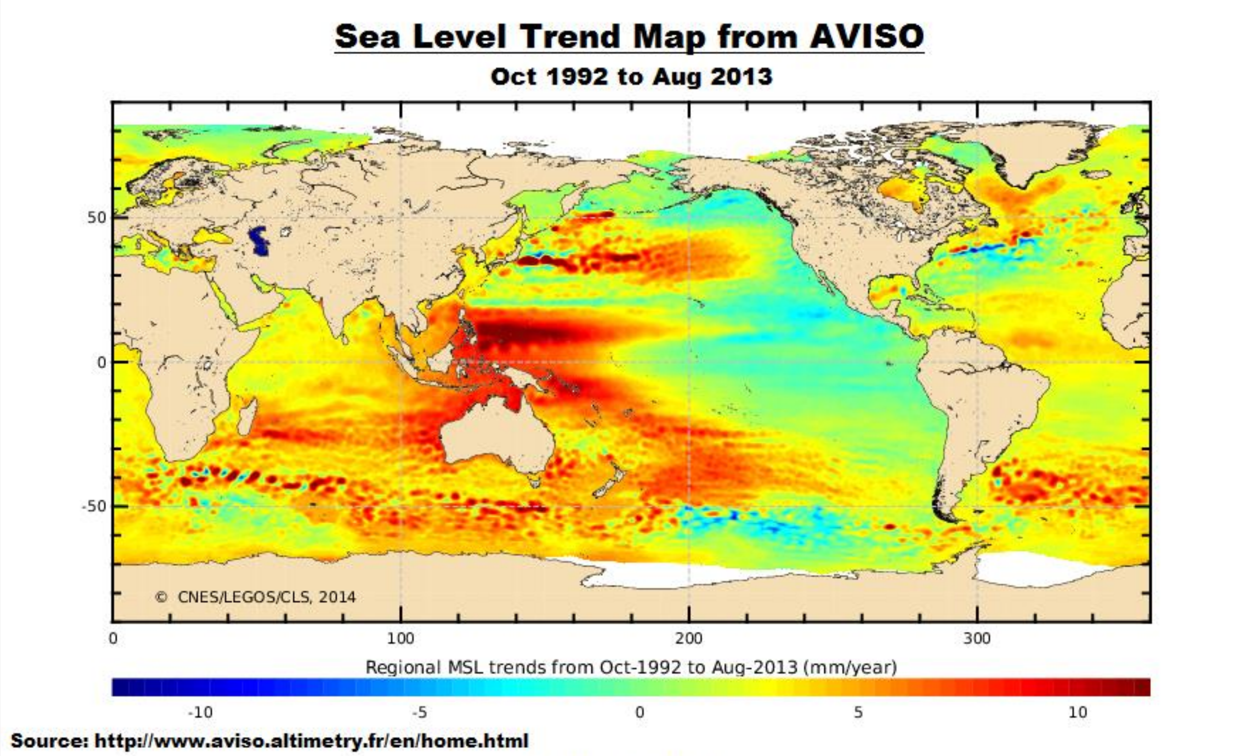


Figure 1.16-6

The AVISO web page states:

> *The rise in the level of the oceans is far from uniform. In fact, while in certain ocean regions the sea level has indeed risen (by up to 20 millimetres a year in places), in others it has fallen an equivalent amount. These regional differences, observed by* Topex/Poseidon *since 1993, mostly reflect sea level fluctuations over several years., estimates of the rise in sea level-now running at 2.5 millimetres a year-have gained in accuracy.*

And the caption for the illustration reads:

> *Combined map of regional patterns of observed sea level (in mm/year). This map can be obtained using gridded, multi-mission Ssalto/Duacs data since 1993, which enable the local slopes to be estimated with a very high resolution (1/3 of a degree on a Mercator projection). Isolated variations in* MSL *are thus revealed, mainly in the major ocean currents. (Credits* CLS/Cnes/Legos*).*

While the rise in sea level is a concern, it is obviously a regional concern. And coastal communities are taking measures to try to adapt to the inevitable rising sea levels.

POST-GLACIAL REBOUND OR GLOBAL ISOSTATIC ADJUSTMENT

We mentioned post-glacial rebound earlier. A quick explanation: During the last ice age, glaciers grew to enormous heights, some as high as 3 kilometers (almost 2 miles). The weight of all of the glacial ice pushed down on land surfaces. After the peak of the last ice age, the glaciers have been melting, and through melting, the glaciers are returning back to the oceans the water they once held on land. Because the land is no longer carrying that extra weight of ice, land surfaces in some parts of the globe are now rising, rebounding. And as mentioned earlier, the rate at which some ocean-side locations are rebounding is faster than sea levels are rising. So for those areas, their relative sea levels are falling.

Something else to consider: During the ice age, as the glaciers pushed down on the land surfaces below them, the Earth's crust had to rise elsewhere, like below the surface of the oceans. Think of a balloon; if you push down on one part, the balloon grows somewhere else. This rise in the ocean floor was also aided by the drop in the weight of water in the oceans during the ice age, since so much water was then on land in the form of ice. So now, with the Earth's surfaces still adjusting for the massive reduction of glacial ice on land, the physical size of the oceans are growing. This increase in the size of the oceans offsets about 10% of the rise in sea level.

Scientists account for that increase in the size of the oceans with an adjustment called "global isostatic adjustment". The Sea Level Research Group at the University of Colorado includes a discussion of this adjustment in their FAQ webpage What is glacial isostatic adjustment (GIA), and why do you correct for it? There, they begin their answer:

> *The correction for glacial isostatic adjustment (GIA) accounts for the fact that the ocean basins are getting slightly larger since the end of the last glacial cycle. GIA is not caused by current glacier melt, but by the rebound of the Earth from the several kilometer thick ice sheets that covered much of North America and Europe around 20,000 years ago. Mantle material is still moving from under the oceans into previously glaciated regions on land. The effect is that currently some land surfaces are rising and some ocean bottoms are falling relative to the center of the Earth (the center of the reference frame of the satellite altimeter). Averaged over the global ocean surface, the mean rate of sea level change due to GIA is independently estimated from models at -0.3 mm/yr (Peltier, 2001, 2002, 2009; Peltier & Luthcke, 2009).*

So of the 3.2 mm/year trend in satellite-era sea level, 0.3 mm/year is global isostatic adjustment for the effects of post-glacial rebound. In other words, the satellite-based altimetry data have a fudge factor that increases the observed sea level rise by about 10% to account for deepening ocean floors and rising shorelines.

But we're interested in the sea levels relative to the shorelines, so the global isostatic adjustment skews those results. Global isostatic adjustments are apparently preferred for scientific discussions, but they exaggerate the rate of rise relative to the shores.

Now let's add another factor. While some parts of the Earth's land masses are rising relative to sea level because of post-glacial rebound, others are dropping because of subsidence.

SUBSIDENCE

Subsidence is the drop in the surface of the Earth relative to sea level. One of the leading contributors to subsidence for some coastal cities is the pumping of water from belowground. Subsidence due to groundwater pumping can present a greater risk to some coastal communities than the actual rise in sea levels. This was the subject of a recent study: Erkens et al. (2014) Sinking Coastal Cities. The abstract begins:

> *In many coastal and delta cities land subsidence now exceeds absolute sea level rise up to a factor of ten. Without action, parts of Jakarta, Ho Chi Minh City, Bangkok and numerous other coastal cities will sink below sea level. Land subsidence increases flood vulnerability (frequency, inundation depth and duration of floods), with floods causing major economic damage and loss of lives. In addition, differential land movement causes significant economic losses in the form of structural damage and high maintenance costs. This effects roads and transportation networks, hydraulic infrastructure – such as river embankments, sluice gates, flood barriers and pumping stations -, sewage systems, buildings and foundations. The total damage worldwide is estimated at billions of dollars annually.*
>
> *Excessive groundwater extraction after rapid urbanization and population growth is the main cause of severe land subsidence. In addition, coastal cities are often faced with larger natural subsidence, as they are built on thick sequences of soft soil.*

For a further introductory discussion, see the article at MailOnline.com titled Forget global warming and melting polar caps - groundwater extraction is causing cities to SINK beneath sea level.

SUMMARY

This chapter opened: For many people, especially for persons living near the coasts, sea level is the critical metric associated with global warming and climate change.

Sea levels have risen since the peak of the last ice age, and, if history repeats itself, they will continue to rise to the heights achieved during the last interglacial: 5 to 10 meters (16 to 32 feet) higher.

But as discussed in this chapter, there are a multitude of factors that can contribute to the rise, or fall, in local sea level. Rising sea levels are, therefore, a local concern, as are steps to combat it, as I've noted numerous times in this chapter. Many countries and communities are already implementing measures to reduce the impacts of rising sea levels—employing methods designed specifically for their location.

Assuming that man-made greenhouse gases have contributed to the rate at which global sea levels are rising, curtailing man-made greenhouse gas emissions would only slow the rate, not stop it. Then again, The Houston & Dean (2010) Sea-Level Acceleration Based on U.S. Tide Gauges and Extensions of Previous Global-Gauge Analyses found that the rise in sea levels had not accelerated with global warming.

WHAT ABOUT THE IMPACTS OF RISING SEA LEVELS ON CORAL ATOLLS?

And just in case you're worried about coral atolls and the people living there, there is more than one study that found that the growth of coral atolls can easily keep up with the rate of sea level rise. Examples:

- Kench et al. (2015) Coral islands defy sea-level rise over the past century: Records from a central Pacific atoll and
- Webb et al. (2010) The dynamic response of reef islands to sea-level rise: Evidence from multi-decadal analysis of island change in the Central Pacific.

Another way to put this in perspective is, sea levels since the end of the last ice age had at times (for hundreds if not thousands of years) risen at much higher rates than they have recently or are expected to rise in the future, refer back to Figure 1.16-1. Yet the atolls we see today met the challenges of keeping up with and thriving during those sea level rises.

1.17 – Global Warming Since 1880 Has Not Been Continuous

In this chapter, we'll illustrate that there are multidecadal variations in the rates of global surface warming, but that there are differences in those variations depending on the long-term temperature reconstruction.

Global surface temperatures have warmed since the late 1800s, but the warming has not been continuous or linear. Before the recent slowdown in surface warming, there were two multidecadal warming periods since 1880 and two periods when the global surface temperatures either cooled or remained relatively flat. The IPCC acknowledged that in their 4th Assessment Report. See Chapter 3 Observations: Surface and Atmospheric Climate Change of the IPCC's AR4. Under the heading of "3.2.2.5 Consistency between Land and Ocean Surface Temperature Changes", the IPCC states with respect to the surface temperature variations over the period of 1901 to 2005 (page 235):

> *Clearly, the changes are not linear and can also be characterized as level prior to about 1915, a warming to about 1945, leveling out or even a slight decrease until the 1970s, and a fairly linear upward trend since then (Figure 3.6 and FAQ 3.1).*

The multidecadal variability differs between global surface temperature datasets. This depends primarily on the sea surface temperature reconstruction employed by the supplier of global temperature data. In this chapter we'll look at two suppliers, using different sea surface temperature data, and also break the data down into Northern and Southern Hemispheres. Let's first look at the GISS Land-Ocean Temperature Index (LOTI) data. GISS uses the NOAA ERSST sea surface temperature data (as does the NCDC). But NOAA made some drastic changes to their ERSST data and they make subtle differences in the multidecadal variability. So we'll examine new and former (pre-June 2015) versions of the GISS product. Afterwards, we'll examine the UKMO's HADCRUT4 land+ocean surface temperature data. The UKMO uses the HADSST3 dataset for sea surface temperatures.

Then we'll present the climate model simulations of surface temperatures for the 4 multidecadal periods.

ABOUT THE BREAKPOINTS

The global and hemispheric temperature data are divided into four periods in this chapter:

- 1880 to 1914: the early cooling period
- 1914 to 1945: the early-20th Century warming period

- 1945 to 1975: the mid-20th Century slowdown period
- 1975 to present: the late-20th Century warming period

I have used other start and end years in blog posts and books over the years. The years shown above, though, are being used to avoid claims that the breakpoint years were cherry picked. I compared climate model outputs to global surface temperature in a blog post back in April 2013. The cross post at WattsUpWithThat is Model-Data Comparison with Trend Maps: CMIP5 (IPCC AR5) Models vs New GISS Land-Ocean Temperature Index. There, Dr. Leif Svalgaard, a solar physicist with Stanford University, was displeased with the years I used as breakpoints for the trend analyses, but Dr. Svalgaard took the time to perform statistical analyses of the data to determine the breakpoint years of 1914 and 1945. See his comments here and here. 1975 is a commonly used breakpoint for the transition from the mid-20th Century slowdown and late 20th Century warming period so we'll use it as well.

Between then and now, GISS has switched sea surface temperature data. A breakpoint analysis of their new combined ocean+land surface temperature data would very likely result in different years, but we'll rely on the breakpoints based on the earlier version of the GISS product for consistency. And I'll present the GISS data in their old (pre-June 2015) form and in its current form.

MULTIDECADAL VARIATIONS IN GISS LAND-OCEAN TEMPERATURE INDEX (LOTI) DATA – OLD (PRE-JUNE 2015) VERSION

I wrote this chapter back in 2014, so the last year of the data is 2013. In it, we're presenting the former version of the GISS Land-Ocean Temperature Index (LOTI) with NOAA's ERSST.v3b sea surface temperature data.

Figure 1.17-1 shows the old annual GISS global Land-Ocean Temperature Index (LOTI) data divided into the four multidecadal periods. Also shown are the linear trends.

The old GISS global land+ocean surface temperature data show two very distinct multidecadal warming periods separated by a period when the warming slowed considerably. They also show considerable cooling from the start of the dataset to 1914.

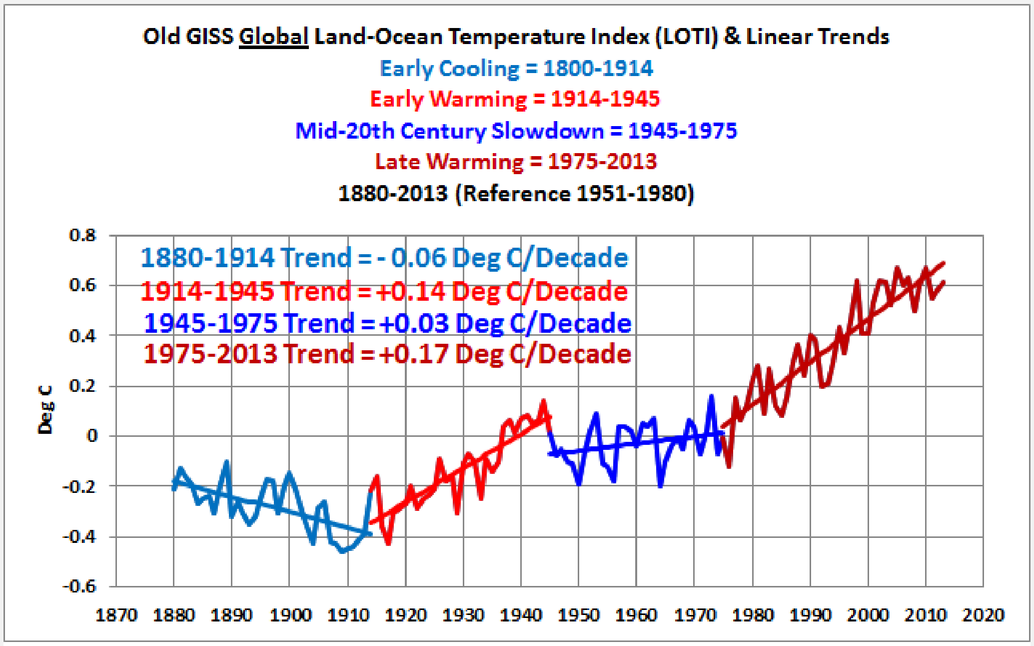


Figure 1.17-1

In the Northern Hemisphere, the variations in the GISS-based (old) surface temperatures become more extreme. See Figure 1.17-2. The trends (warming rates) for the Northern Hemisphere data during the two warming periods are greater than the global data, and the Northern Hemisphere surface temperatures cooled from 1945 to 1975. The cooling rate from 1880 to 1914 is less in the Northern Hemisphere than it is globally.

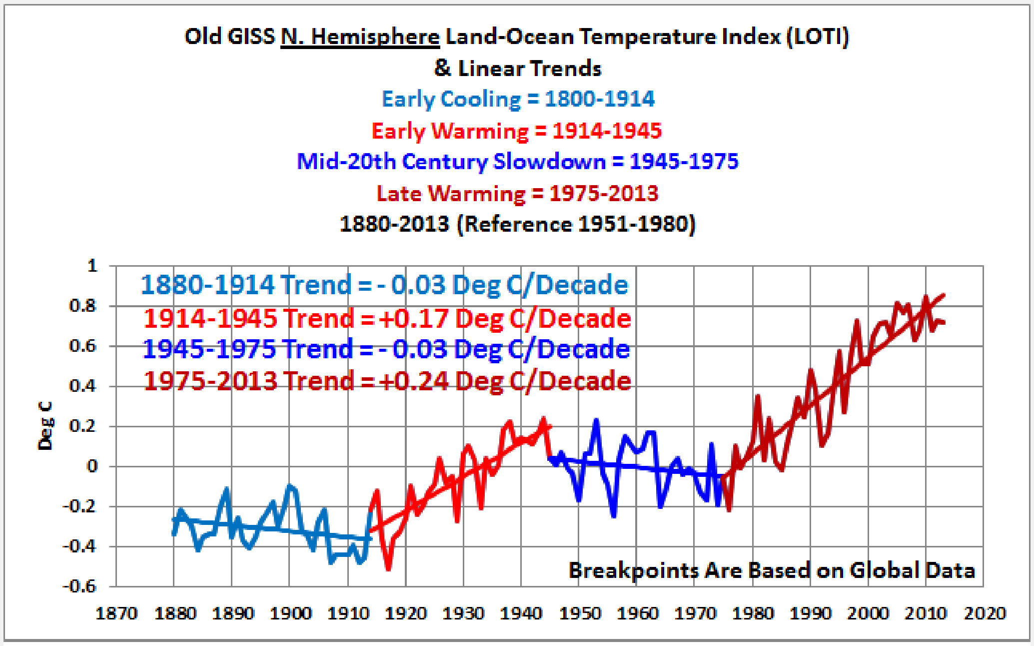


Figure 1.17-2

The old GISS land+ocean temperature data for the Southern Hemisphere show a shorter slowdown/cooling period in the mid-20th Century, as shown in Figure 1.17-3.

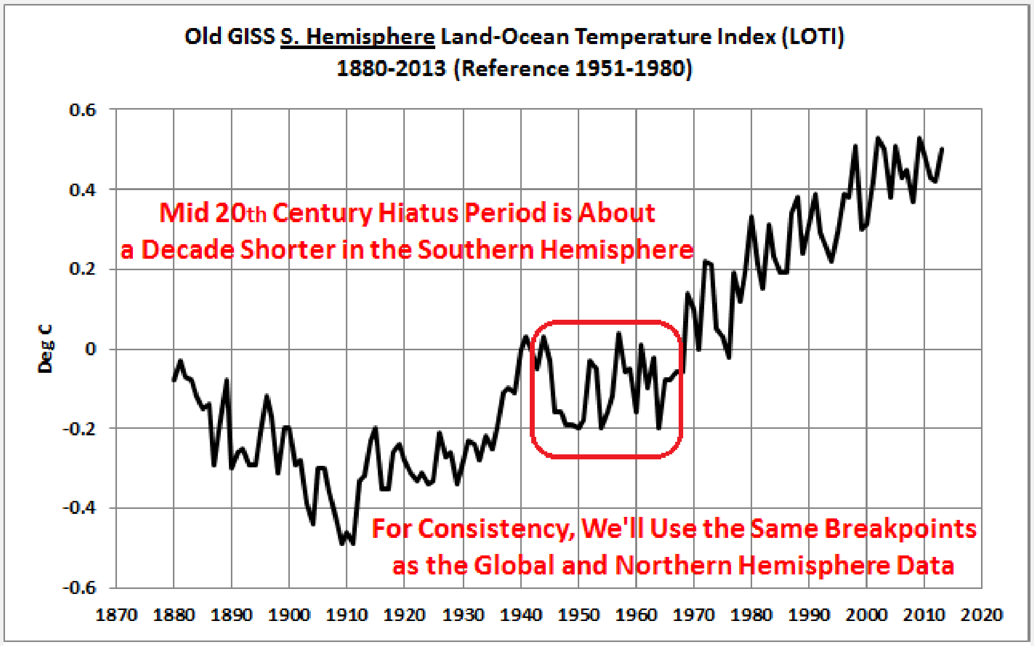


Figure 1.17-3

Even though it will look awkward, for consistency with the global and Northern Hemisphere data, we'll use the same breakpoint years for the Southern Hemisphere data. See Figure 1.17-4.

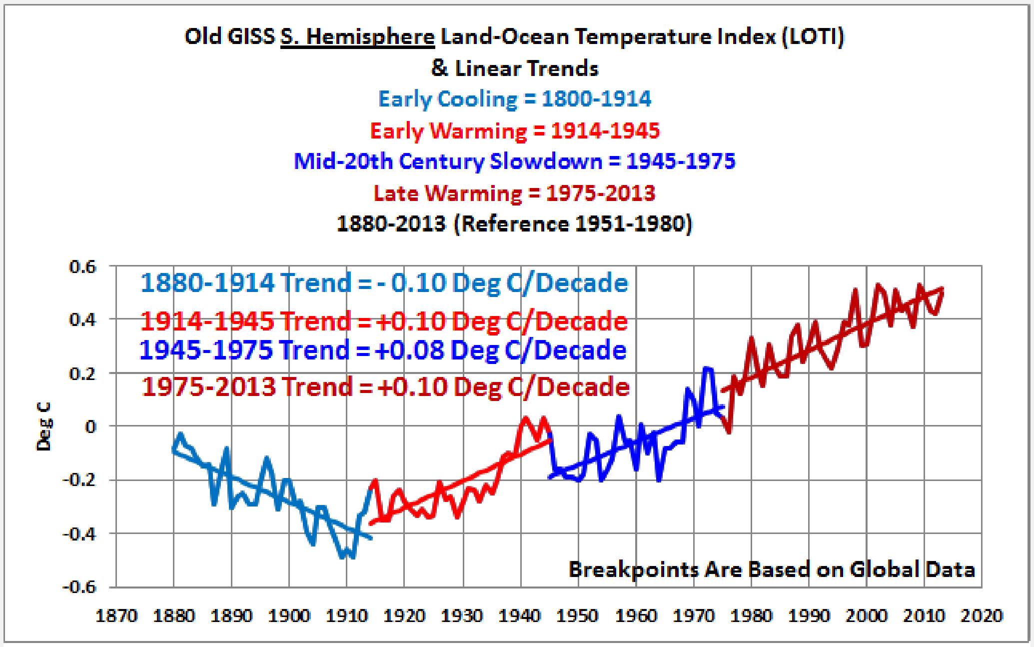


Figure 1.17-4

In fact, because the actual slowdown period was so much shorter in the Southern Hemisphere, the warming rate for 1945 to 1975 is not much different than the warming rates for the two warming periods that flank it, and notice, based on the former (old) GISS product, that the warming rates in the Southern Hemisphere for the periods of 1914-1945 and 1975-2013 are the same at +0.10 deg C/decade. That's odd. According to the forcings used as inputs to the climate models, the warming during the period of 1975-2013 should have happened at a much faster rate than the period of 1914-1945.

Also notice that the warming rates for the old GISS Land-Ocean Temperature Index data in the Southern Hemisphere are considerably lower than they are in the Northern Hemisphere. Last, the cooling in the early part of the data for the Southern Hemisphere is much greater than in the Northern Hemisphere.

MULTIDECADAL VARIATIONS IN GISS LAND-OCEAN TEMPERATURE INDEX (LOTI) DATA – NEW (POST-JUNE 2015) VERSION

GISS changed sea surface temperature products (from the ERSST.v3b reconstruction) to NOAA's new "pause-buster" ERSST.v4 reconstruction with their June 2015 update. This shifted the multidecadal warming and cooling rates a little. But something else appears, especially in the Southern Hemisphere data: an unexplainable spike in surface temperatures in the late-1930s to mid-1940s.

We'll start with the global data and work our way to the Southern Hemisphere.

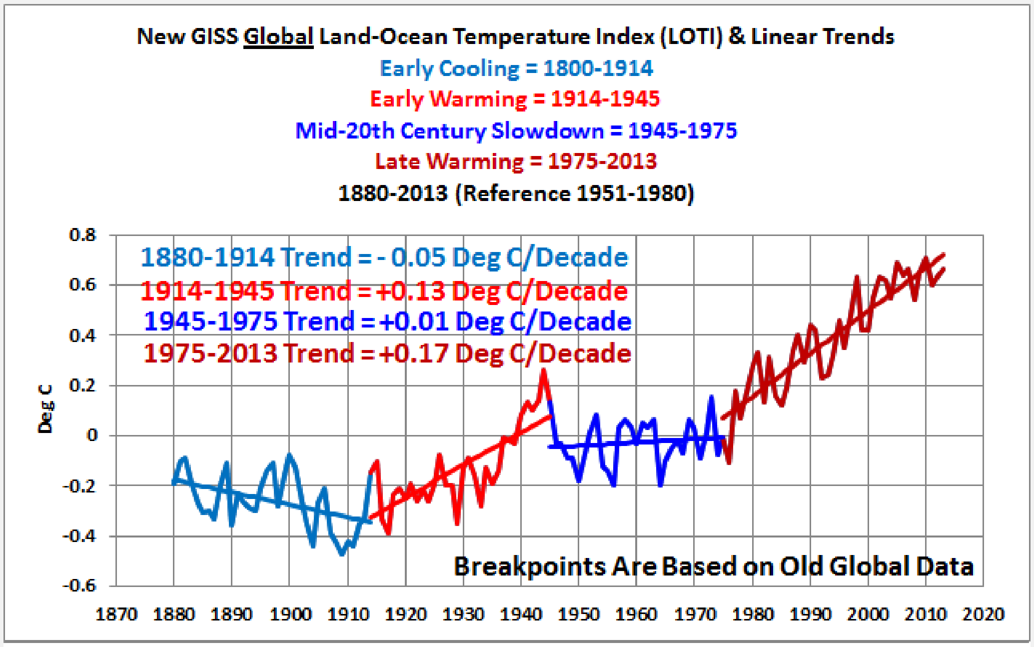


Figure 1.17-5

The changes in the trends will be shown later in Table 1.17-1, but if you were to scroll back and forth between Figure 1.17-1 and Figure 1.17-5, you'd note there was no change in the warming rates during the recent warming period of 1975-2013 with the recent revisions to the GISS product. The noticeable changes appear in the early cooling (1880-1914) and early warming (1914-1945) phases. The cooling rate from 1880-1914 was slowed as was the warming rate from 1914-1945. For the mid-20th Century slowdown period, the new global GISS data show an even slower warming rate from 1945-1975.

The new GISS data for the Northern Hemisphere are shown in Figure 1.17-6. The warming rates are the same during the late 20th-Century warming period, while there are very small changes in the trends of the early warming period (1914-1945) and mid-20th-Century cooling period (1945-1975). The early cooling period trends are the same for the new and old GISS data in the Northern Hemisphere.

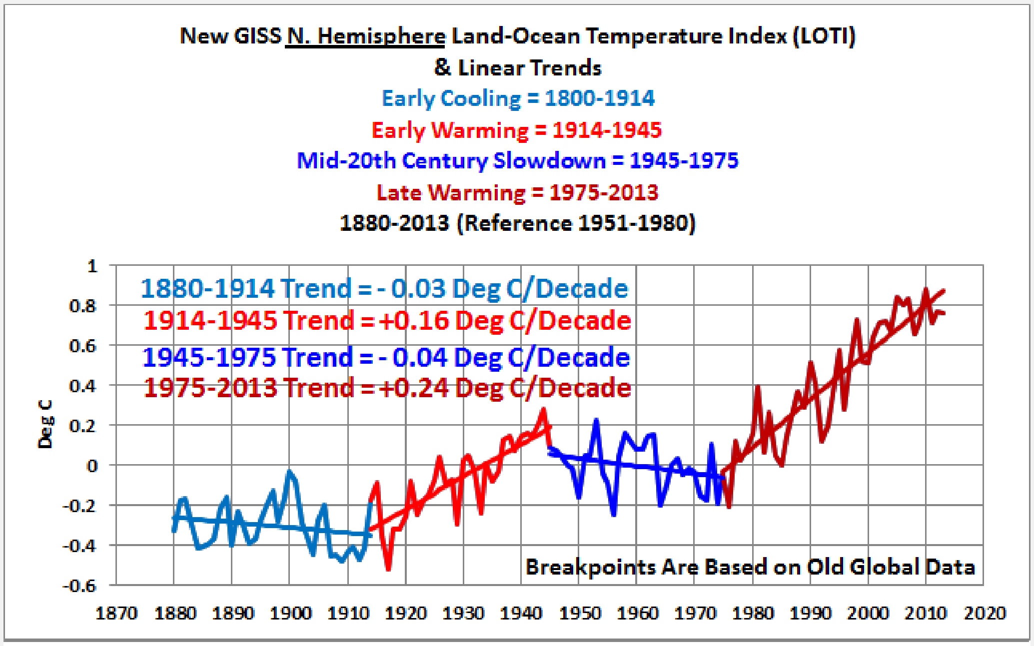


Figure 1.17-6

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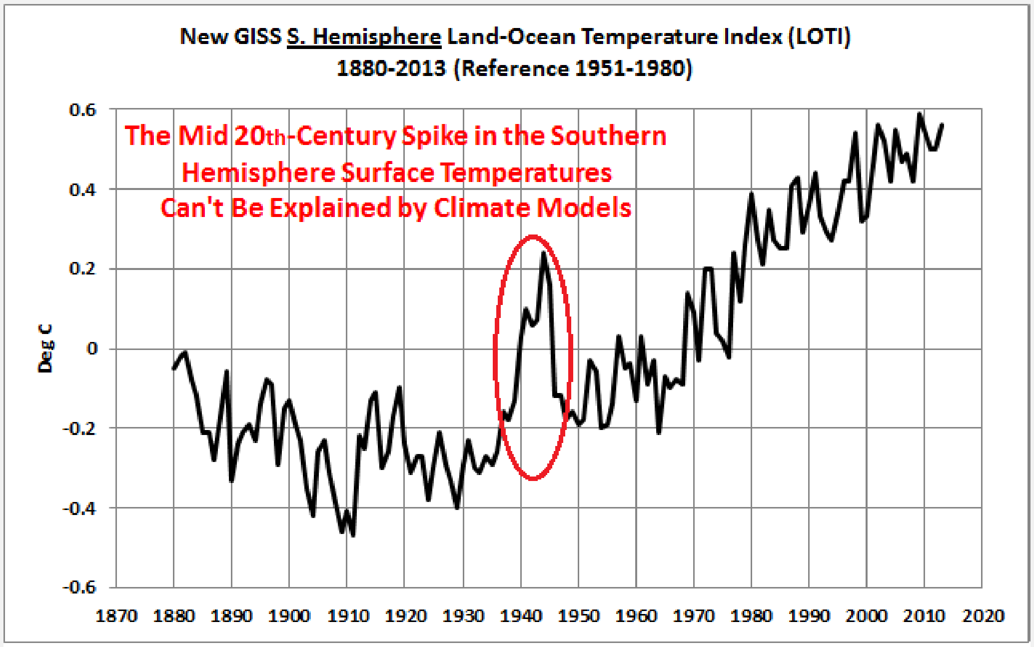

Figure 1.17-7

The real curiosity with the ERSST.v4-based changes to the GISS product comes in the Southern Hemisphere. There is a monumental spike in surface temperatures that starts in the late-1930s and ends in the mid-1940s. See Figure 1.17-7. Climate models can't explain it. It also does not appear in land surface air temperatures. So, not only does it look awkward, but, if it's correct, it suggests that surface temperatures can warm very rapidly without being forced to do so from greenhouse gases, so it creates a big problem for the hypothesis of human-induced global warming. We'll discuss the update to NOAA's ERSST sea surface temperature dataset in more detail in Part 2 (future).

The ERSST-based changes to the GISS Southern Hemisphere surface temperature data didn't change the warming rates in the early warming period (1914-1945) or the late warming period (1975-2013). See Figure 1.17-8. But they slowed the warming rate from 1945-1975, and slowed the cooling rate from 1880-1914.

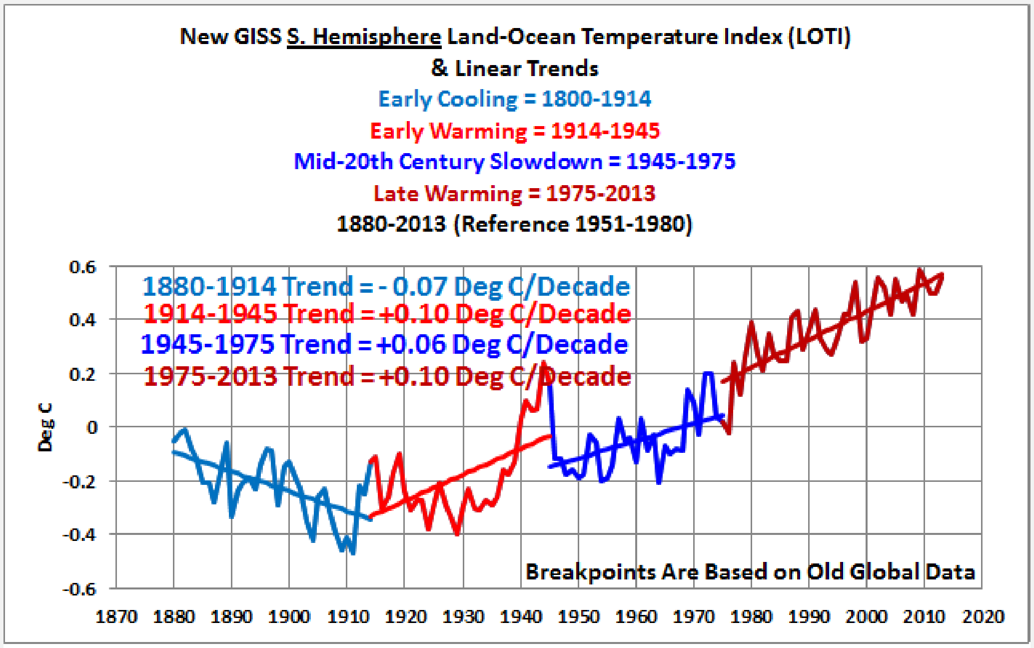

Figure 1.17-8

MULTIDECADAL VARIATIONS IN UKMO HADCRUT4 DATA

The most-noticeable difference between both versions of the global GISS Land-Ocean Temperature Index and the UKMO HADCRUT4 global land+ocean surface temperature data appears during the mid-20th Century period of 1945 to 1975. As shown in Figure 1.17-9, where the GISS LOTI data showed a slowdown in the warming rate during this period, the global HADCRUT4 data show a slight cooling.

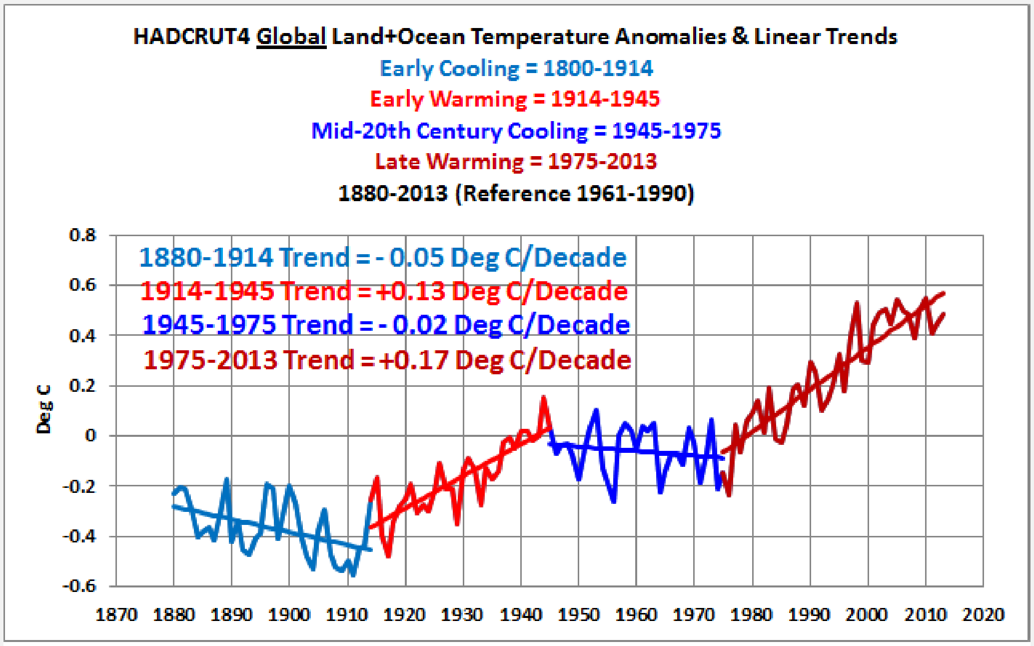

Figure 1.17-9

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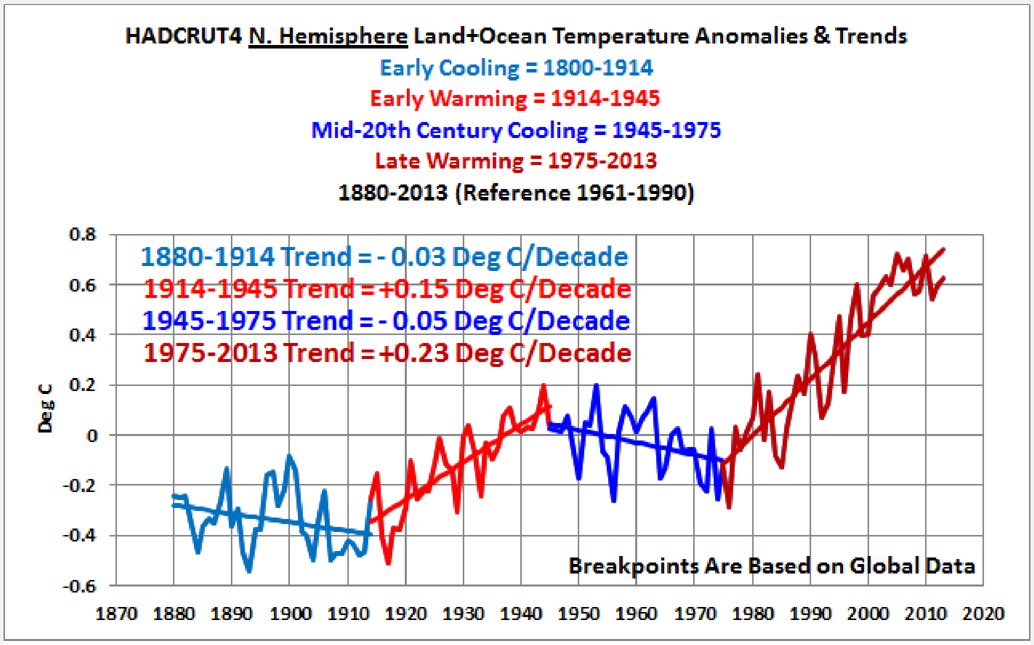


Figure 1.17-10

Like the GISS LOTI data (both recent versions), the multidecadal variations in the surface temperatures for the Northern Hemisphere in the HADCRUT4 data are much more pronounced than the global data, with two distinct warming periods and two definite cooling periods. See Figure 1.17-10 above.

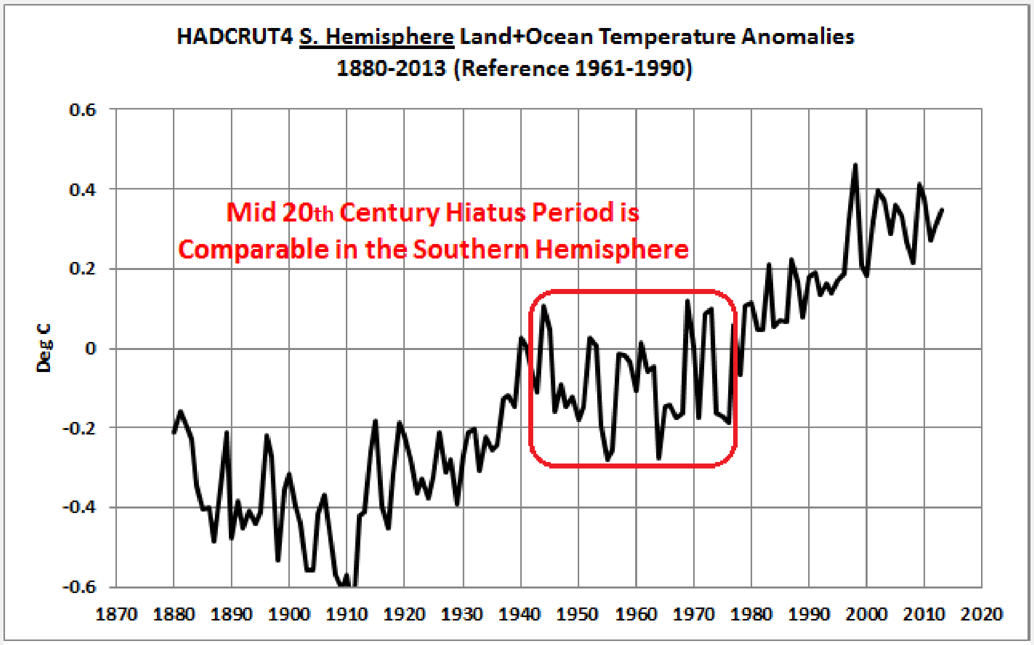


Figure 1.17-11

For the Southern Hemisphere, the mid-20th Century slowdown in warming lasts until the mid-1970s with the HADCRUT4 data. See Figure 1.17-11. (As you'll recall, the slowdown for the Southern Hemisphere with the GISS LOTI data only lasted until the mid-1960s.) As a result, the warming rate during this period with the HADCRUT4 data is very small in the Southern Hemisphere, as shown in Figure 1.17-12. There's also something missing in the HADCRUT4-based Southern Hemisphere surface temperature data: the mid-20th Century spike in the new version of the GISS data.

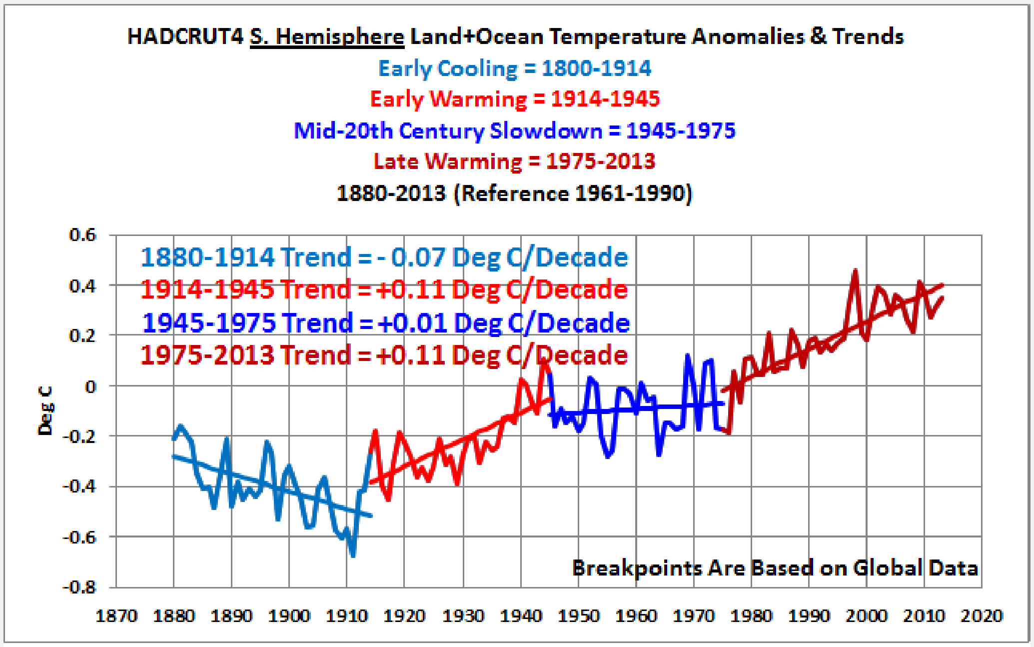


Figure 1.17-12

As noted earlier, the differences in the sea surface temperature datasets employed by GISS and the UKMO are the primary cause of the differences in the multidecadal variations in the surface temperatures. We'll illustrate and discuss this more in the upcoming Part 2 of this book. Because the NCDC uses the same sea surface temperature dataset as GISS for their global land+ocean surface temperature product, the multidecadal variations in the NCDC data are more similar to the GISS data than to the UKMO HADCRUT4 data.

Because the NCDC trends are so similar to those of the GISS data, there's really no reason to present graphs of the NCDC data. However, I have included the NCDC trends later in Table 1-3, which compares the warming and cooling rates for the three primary suppliers of global temperature products during the four multidecadal periods discussed in this chapter. The trends are also shown globally and for the Northern and Southern Hemispheres.

But first, let's take a look at the trends of the climate model simulations of global surface temperatures for the 4 multidecadal periods.

CLIMATE MODELS DO NOT SIMULATE THE MULTIDECADAL VARIATIONS IN GLOBAL SURFACE TEMPERATURES THAT EXIST IN DATA

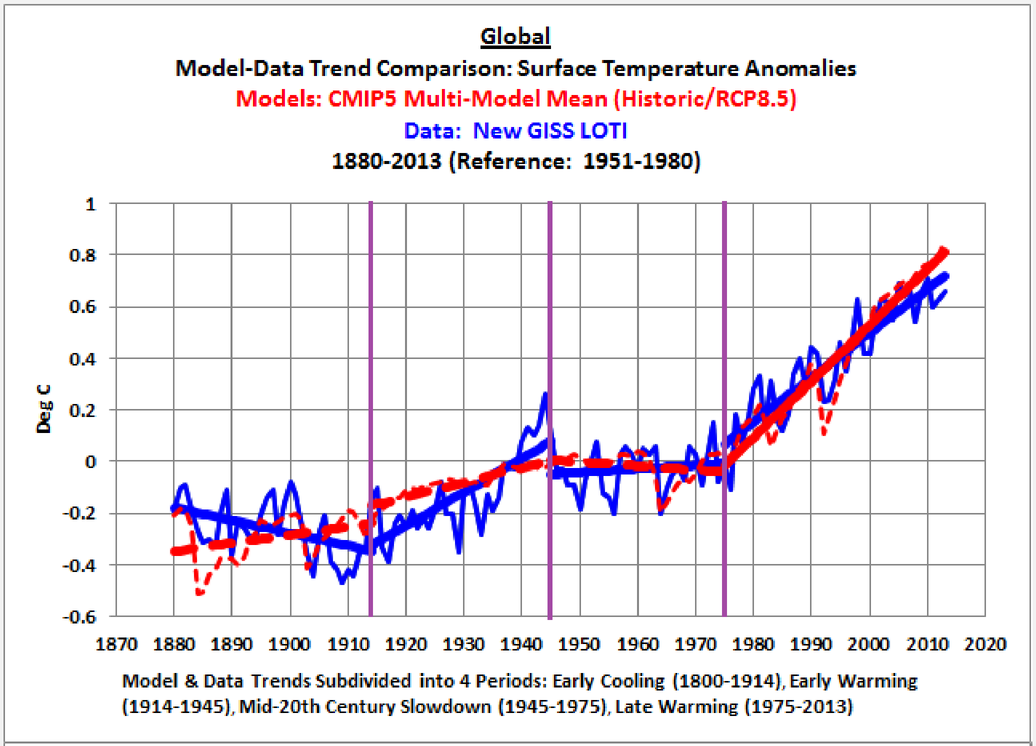
Like most of the model presentations in this book we're using the multi-model mean of the climate models stored in the Coupled Model Intercomparison Project, phase 5 (CMIP5) archive. Those were the models used by the IPCC for their 5th Assessment Report. In the following three illustrations, we're visually comparing the model-simulated versus the observed trends for the four periods presented in this chapter: the early cooling (1880-1914), early warming (1914-1945), mid-20th Century slowdown (1945-1975) and the late warming (1975-2013) periods. The top graph in each presents the new GISS LOTI data (referenced to their standard base years of 1951-1980) and the bottom graph is the UKMO HADCRUT4 land-ocean surface temperature anomalies (referenced to their standard base years of 1961-1990). The different base years do not change the shapes of the curves or their trends; the base years simply shift the points at which the data and models cross zero.

Figure 1.17-13 includes the data and model mean globally, while Figure 1.17-14 compares the model mean and data for Northern Hemisphere surface temperatures. Depending on the dataset, the models have different levels of success at simulating trends during the late warming and the mid-20th Century slowdown periods, both globally and for the Northern Hemisphere. The HADCRUT4 data show less warming during the late warming period, so you can see the greater divergence between the trends for the models and data.

The models fail miserably during the early cooling period of 1880-1914, because they show warming when the data show cooling, both globally and in the Northern Hemisphere. Logically, because the models don't capture that early cooling, they then severely underestimate the warming that took place from the 1910s to the mid-1940s.

Looking at the model-data comparisons for the Southern Hemisphere, Figure 1.17-15, the disparities between the modeled and observed trends during the early cooling and early warming periods are even more severe. The models also grossly overestimate the warming rate during the recent warming period in the Southern Hemisphere. As you'll see in Table 1.17-1, the modeled warming rate for the Southern Hemisphere surface temperatures is 0.17 deg C/decade, while the observed trends are 0.11 deg C/decade for the HADCRUT4 data and 0.10 deg C/decade for the new GISS data.

For the mid-20th Century slowdown period in the Southern Hemisphere, the models perform well compared to the HADCRUT4 data, but fail miserably with the GISS LOTI data.



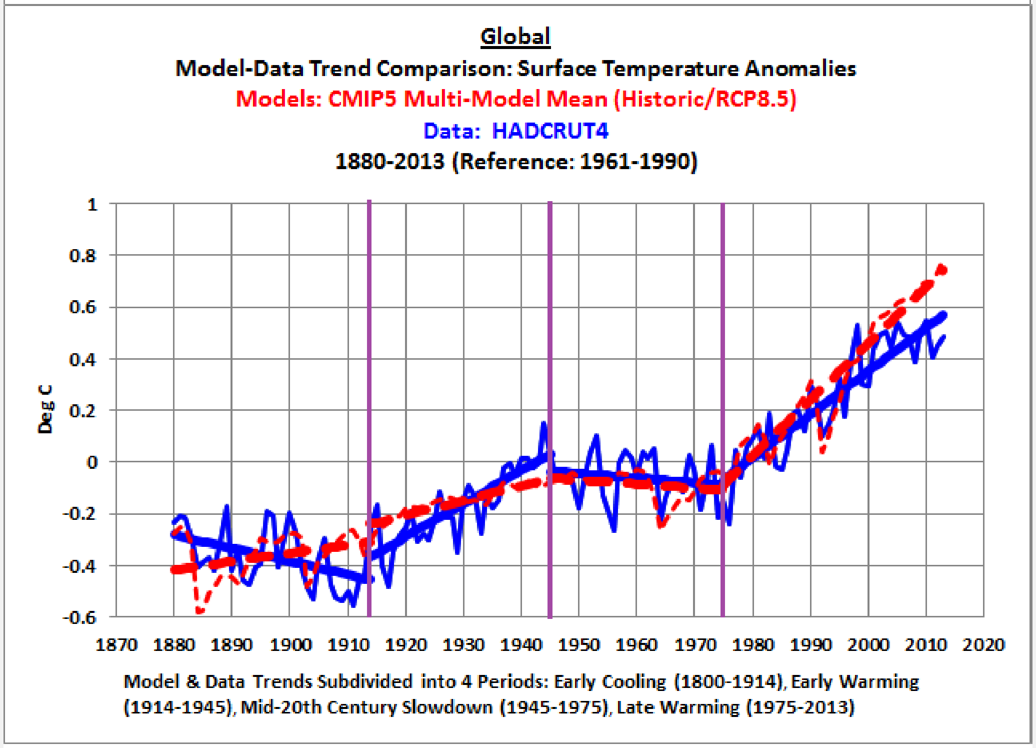


Figure 1.17-13

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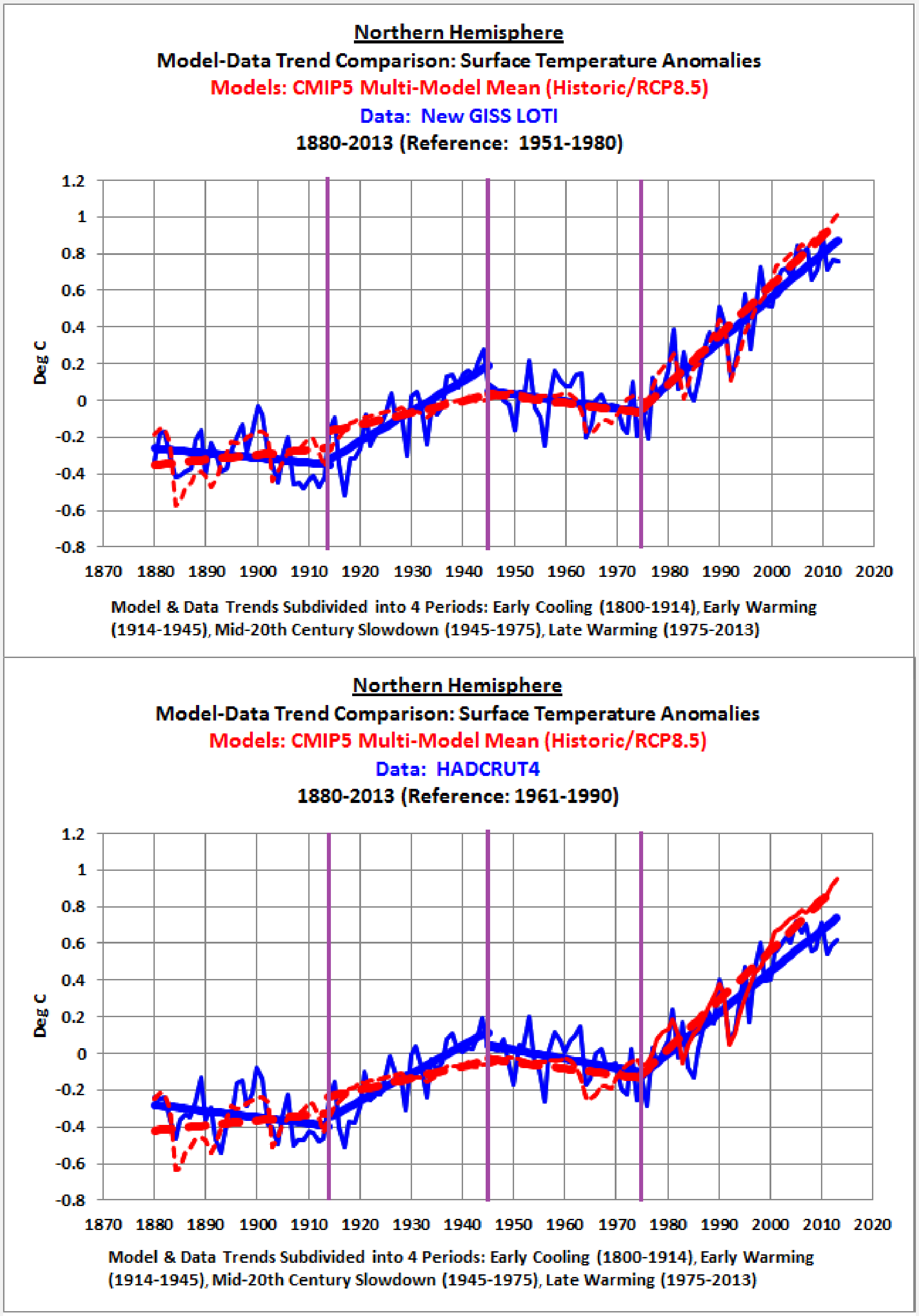

Figure 1.17-14

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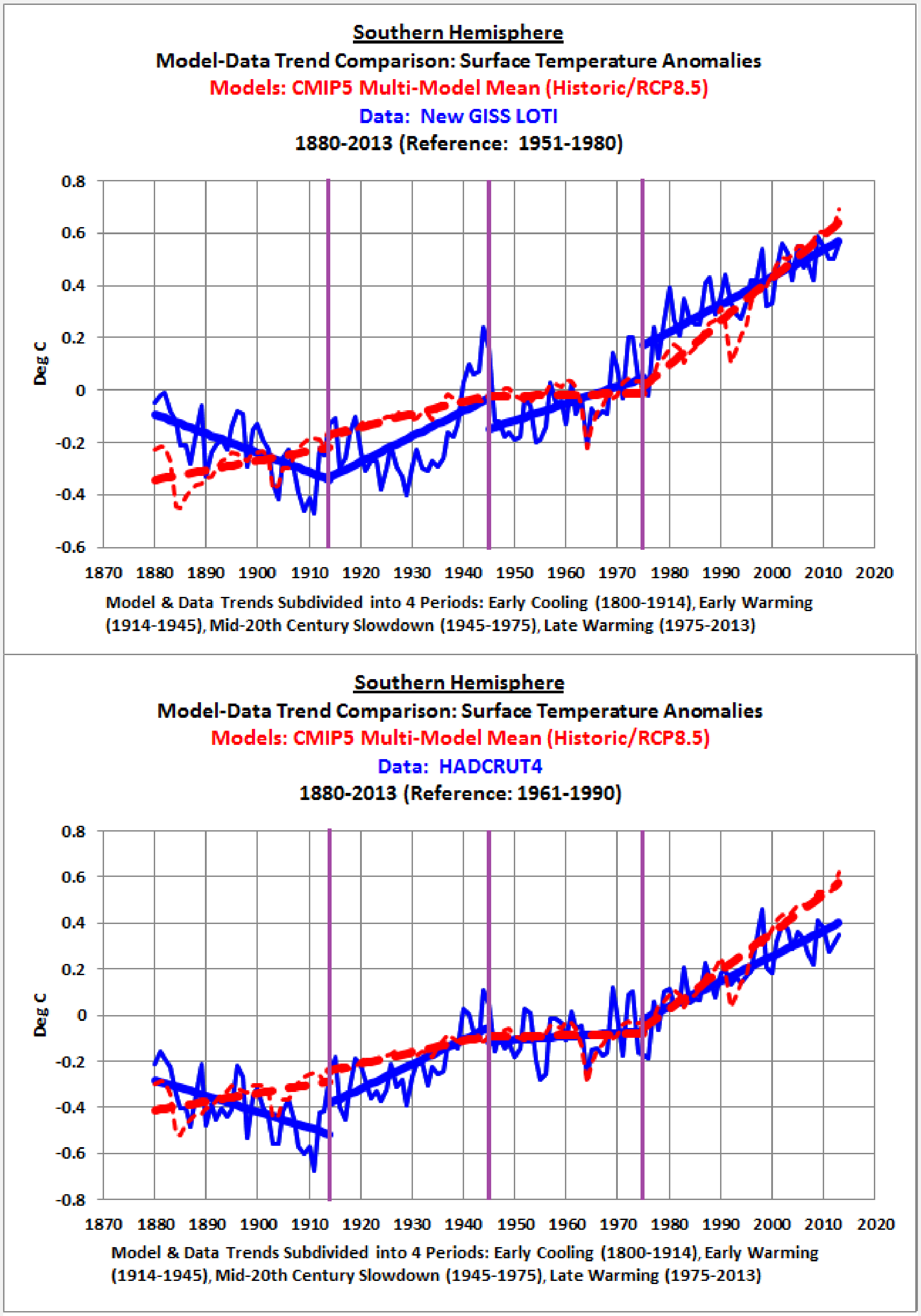


Figure 1.17-15

COMPARISON TABLE

Table 1.17-1 compares the warming and cooling rates for the three primary suppliers of global temperature products during the four multidecadal periods discussed in this chapter. The NCEI (formerly NCDC) product is the newer version with the ERSST.v4 data. I've also included the old and new versions of the GISS reconstruction. The trends are shown globally and for the Northern and Southern Hemispheres. Also included in Table 1.17-1 are the trends for the climate models, broken down the same way.

When looking at the disparity between the trends for the models and data, consider this: the observed warming rate for global surface temperatures from 1880 to 2013 is +0.067 deg C/decade for the new GISS LOTI data and +0.063 deg C/decade for the HADCRUT4 data. It's that minor long-term warming rate that's generating all of the fuss.

Table 1.17-1 Multidecadal Global Surface Temperature Trends
From The Three Primary Data Suppliers & CMIP5 Climate Models

PERIOD	REGION	TRENDS (Deg C/Decade)				
		GISS Old	GISS New	NCEI	HADCRUT4	CMIP5 Models
1880-1914	Global	-0.06	-0.05	-0.06	-0.05	0.03
	N. Hemisphere	-0.03	-0.03	-0.05	-0.03	0.03
	S. Hemisphere	-0.1	-0.07	-0.07	-0.07	0.04
1914-1945	Global	0.14	0.13	0.13	0.13	0.06
	N. Hemisphere	0.17	0.16	0.15	0.15	0.06
	S. Hemisphere	0.1	0.1	0.11	0.11	0.05
1945-1975	Global	0.03	0.01	0.01	-0.02	-0.02
	N. Hemisphere	-0.03	-0.04	-0.03	-0.05	-0.04
	S. Hemisphere	0.08	0.06	0.06	0.01	0
1975-2013	Global	0.17	0.17	0.16	0.17	0.22
	N. Hemisphere	0.24	0.24	0.22	0.23	0.27
	S. Hemisphere	0.1	0.1	0.1	0.11	0.17

MODEL-DATA COMPARISONS OF 30-TRENDS IN GLOBAL SURFACE TEMPERATURES

The differences between models and data may have been hard to see in Figures 1.17-13 through 1.17-15. There's another way to display the differences in the multidecadal variations in the data and model outputs: using 30-year trends. Why 30 years? Recall from Chapter 1.5, the World Meteorological Organization defines climate on their Frequently Asked Questions webpage as:

> *Climate in a narrow sense is usually defined as the "average weather," or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or*

millions of years. The classical period is 30 years, as defined by the World Meteorological Organization (WMO).

Figure 1.17-16 contains two model-data comparisons of 30-year trends (trailing) in global surface temperatures.

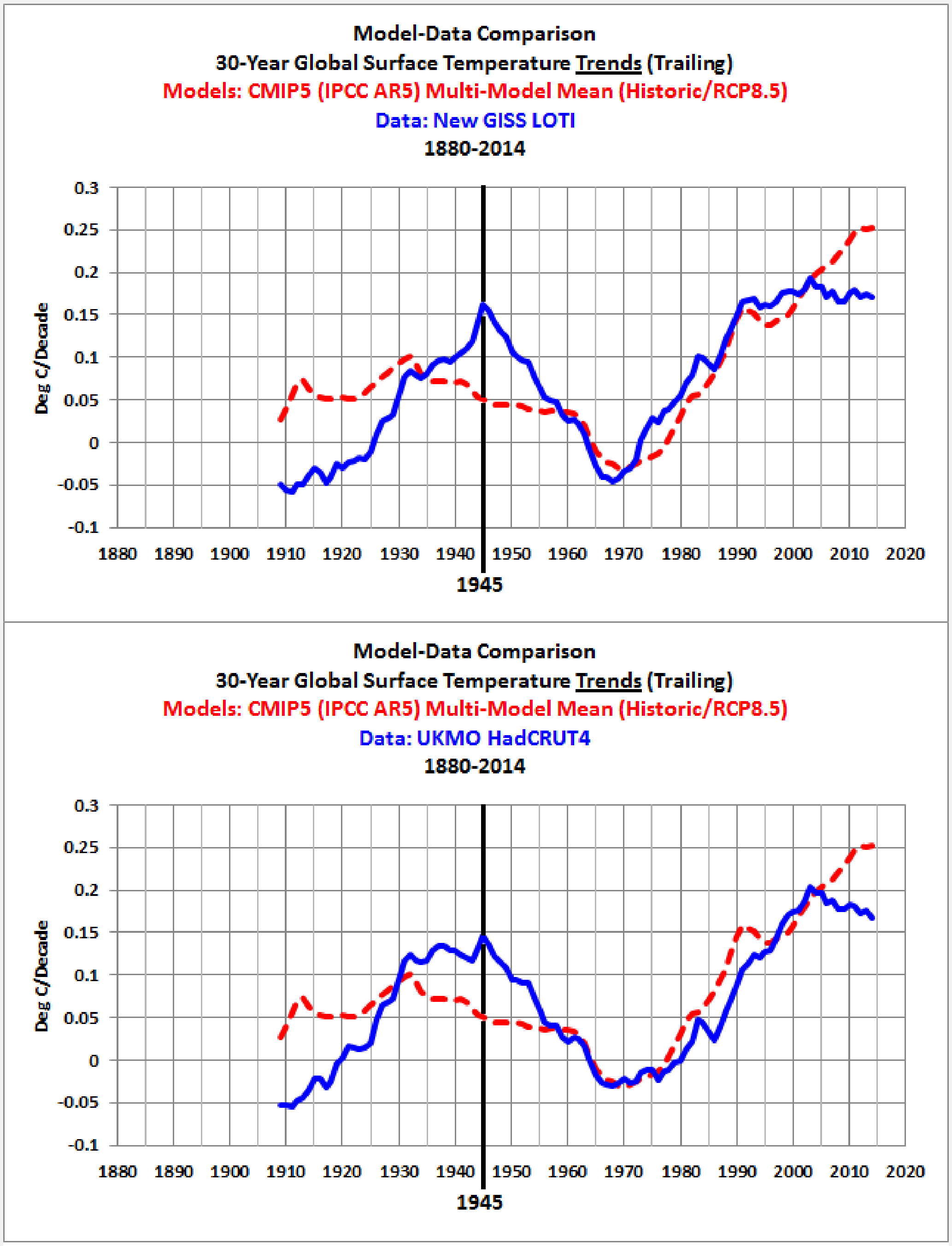


Figure 1.17-16

The models in both graphs are represented by the multi-model mean of the climate models stored in the CMIP5 archive, which were used by the IPCC for their 5th

Assessment Report. The model outputs are available through the KNMI Climate Explorer. For the data, the top graph includes the GISS Land-Ocean Temperature Index (LOTI), while the bottom graph includes the HadCRUT4 reconstruction from the UKMO.

An explanation of what's being presented in Figure 1.17-16: The final data points are the 30-year trends in deg C/decade for the period of 1985-2014, the data points immediately before it show the linear trends from 1984-2013, etc., working back in time until the first data points at 1909, which show the 30-year linear trends from 1880-1909. I've used the term *Trailing* to signify that the trends are shown at last years the 30-year periods.

I've highlighted the year 1945 in both graphs. With both the GISS LOTI and UKMO HadCRUT4 global surface temperature reconstructions, the warming rates (the linear trends) for the early warming period both peak at the 30-year period ending in 1945. And the two 30-year trends are roughly the same at about 0.15 deg C/decade. On the other hand, the model mean (the consensus or groupthink of the modeling groups) show global surface temperatures should only have warmed about 0.05 deg C/decade for that 30-year period ending in 1945, if global warming was only driven by the greenhouse gases and other factors that are used to force the models.

In other words, Figure 1.17-16 indicates that global surface temperatures are capable of warming naturally at rates that are about 3 times faster than hindcast by the climate models. That raises a very important question: how much of the warming during the recent warming period is also natural? The fact that the models better align with the data during this period doesn't mean the surface temperatures were forced to warm at the same rates as the models. Surface temperatures have already shown they are capable or warming at rates that are 3-times higher than the models. The better alignment of models and data in recent decades simply indicates the models are tuned to simulate the warming then.

Figure 1.17-16 strongly suggests that climate model projections of future global warming are at about two-times too high.

CLOSING TO CHAPTER

All in all, since 1880, global surface temperatures first cooled from 1880 to about 1914. Then there are two warming periods separated by a period when global surface temperatures either warmed at a much slower pace or cooled. Overall, the warming has exceeded the cooling, so global surface temperatures have warmed since 1880.

Or we could say that, while global surface temperatures have warmed since 1880, there were multidecadal variations in the rates at which it warmed.

Now the question is, based on past history, should we expect the multidecadal variations to continue? That is, should we now expect a multidecadal period when the warming of global surface temperatures slows or possibly cools? The climate models used by the IPCC are not programmed so that the multidecadal variations to continue. Their projections of future global surface temperatures are based on the latest upswing in surface temperatures, without considering the possibility of long-term multidecadal variations in the warming rate.

And because the climate models do not simulate the multidecadal variability exhibited by the instrument temperature record, data suppliers like NOAA are trying hard to remove the current slowdown in the warming rate of their global surface temperature products.

The model outputs serve as a reference for how global surface temperatures should vary if the multidecadal variations were dictated by the forcings that are used to drive the models. However, we've seen in the early cooling period that global surface temperatures can cool without being forced to do so. Even more critical to discussions of long-term global warming, based on the 30-year trends ending in 1945 shown in Figure 1.17-16, we've seen that global surface temperatures can warm at rates that are three times higher than the forced rates of the climate models. This suggests that a major portion of the warming since the mid-1970s had occurred naturally.

Because climate models cannot simulate naturally occurring coupled ocean-atmosphere processes that enhance or suppress global warming, they have no value when attempting to attribute global warming to mankind…or when attempting to predict how climate may change in the future based on projections of future CO_2 emissions.

1.18 – What is Polar Amplification?

There are a number of interesting naturally occurring climate-related phenomena. One is "polar amplification", which takes place primarily in the Arctic. As a result, it is sometimes called Arctic Amplification. The opening paragraph of the Polar Amplification post at RealClimate provides a good overview. As you'll recall, RealClimate is a blog hosted by members of the climate science community. But the post on Polar Amplification was prepared by Cecilia Bitz of the University of Washington. Dr. Bitz writes:

> *"Polar amplification" usually refers to greater climate change near the pole compared to the rest of the hemisphere or globe in response to a change in global climate forcing, such as the concentration of greenhouse gases (GHGs) or solar output (see e.g. Moritz et al 2002). Polar amplification is thought to result primarily from positive feedbacks from the retreat of ice and snow. There are a host of other lesser reasons that are associated with the atmospheric temperature profile at the poles, temperature dependence of global feedbacks, moisture transport, etc. Observations and models indicate that the equilibrium temperature change poleward of 70N or 70S can be a factor of two or more greater than the global average.*

While the polar-amplified warming of the Arctic occurs naturally, we have been led to believe that polar amplification has been enhanced by man-made greenhouse gases. And rarely is it explained that polar amplification works two ways; that is, it also exaggerates cooling in the Arctic during multidecadal periods when the Northern Hemisphere cools.

Because polar amplification is primarily a Northern Hemisphere phenomenon, let's first examine the trends in surface temperature record, starting in the early 1900s. And we'll divide the time into three periods, using the same timeframes as the last chapter: 1914-1945 for the early-warming period, 1945-1975 for the mid-century slowdown, and 1975-2014 for the recent-warming period.

Figure 1.18-1 illustrates the warming rates (trends in deg C/decade) in global surface temperatures since 1914 using the new GISS LOTI (Land-Ocean Temperature Index) data on a zonal-mean (latitude-average) basis. Explanation: The units for the vertical (y) axis are in deg C per decade (deg C/decade), and they present the trends in surface temperatures (the warming and cooling rates). The horizontal (x) axis is latitude, with the South Pole at -90 (90S), the North Pole at 90 (90N) and with the equator at 0. To create a graph like the one shown in Figure 1.18-1, temperature data is downloaded in 5 degree latitude bands. For Figure 1.18-1, the trends start at -62.5 (62.5S). Those first data points at 62.5S are based on surface temperature data for the latitudes of 65S-60S. The next data points to the right at 57.5S are based on the surface temperatures for the latitude band of 60S-55S. The process continues in 5-degree latitude bands northward to the North Pole.

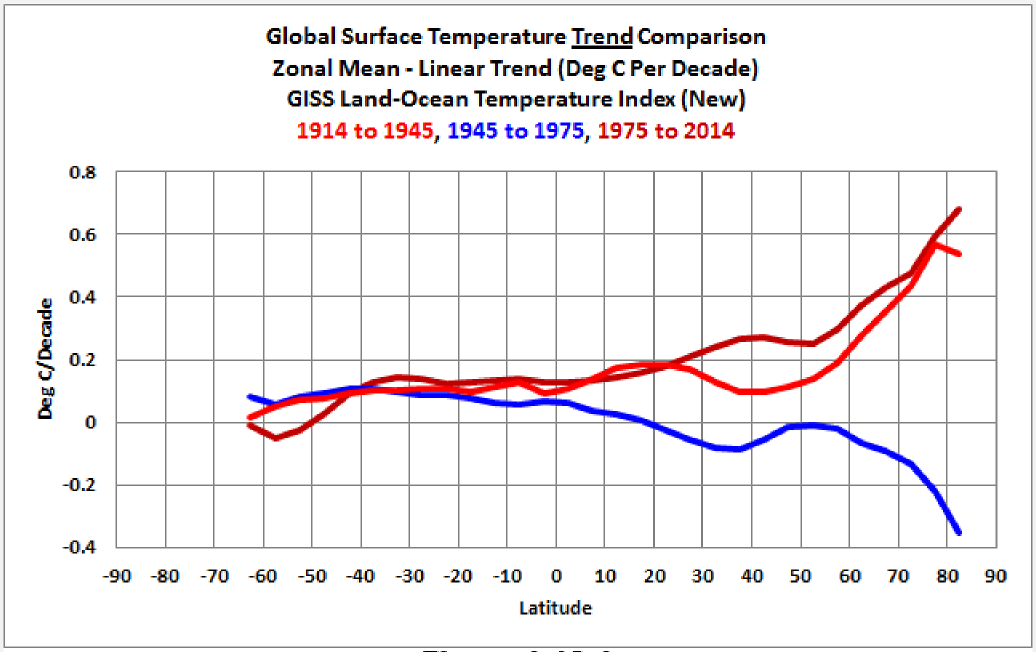


Figure 1.18-1

The data were divided into three periods: 1914-1945, 1945-1975, and 1975-2014. Polar (Arctic) amplified warming occurred during the two warming periods of 1914-1945 and 1975-2012. Polar amplification also works in the other direction, too. That is, it can exaggerate the **cooling** trends in the Northern Hemisphere, as seen during the period of 1945-1975.

As you'll note, I have not presented trends for Antarctica and for most of the Southern Ocean that surrounds it. Land surface temperature data for Antarctica does not begin until the 1950s, and there is too little sea surface temperature source data in the Southern Ocean before the satellite era to show the trends there.

Let's focus on the warming rates in the high latitudes of the Northern Hemisphere for a moment. You'll notice that the polar amplification signals are comparable during the two warming periods of 1914-1945 and 1975-2014. Now consider that the emissions of man-made greenhouse gases increased at a much slower rate during the earlier warming period than the more recent warming period. How then can man-made greenhouse gases be said to have caused the polar-amplified warming for the period 1975-2012, when the earlier warming period shows similar polar-amplified warming with much less forcing from man-made greenhouse gases?

POLAR AMPLIFICATION IS A PHENOMENON THAT PRESENTS ITSELF IN LAND SURFACE AIR TEMPERATURE DATA, BUT NOT ALL SEA SURFACE TEMPERATURE DATASETS

Figure 1.18-2 compares warming rates on a zonal-means basis for two datasets: 1) Reynolds OI.v2 sea surface temperature data and 2) CRUTEM4 land surface air temperature data. The time period extends from the start of the Reynolds OI.v2 data (November, 1981) to July, 2013.

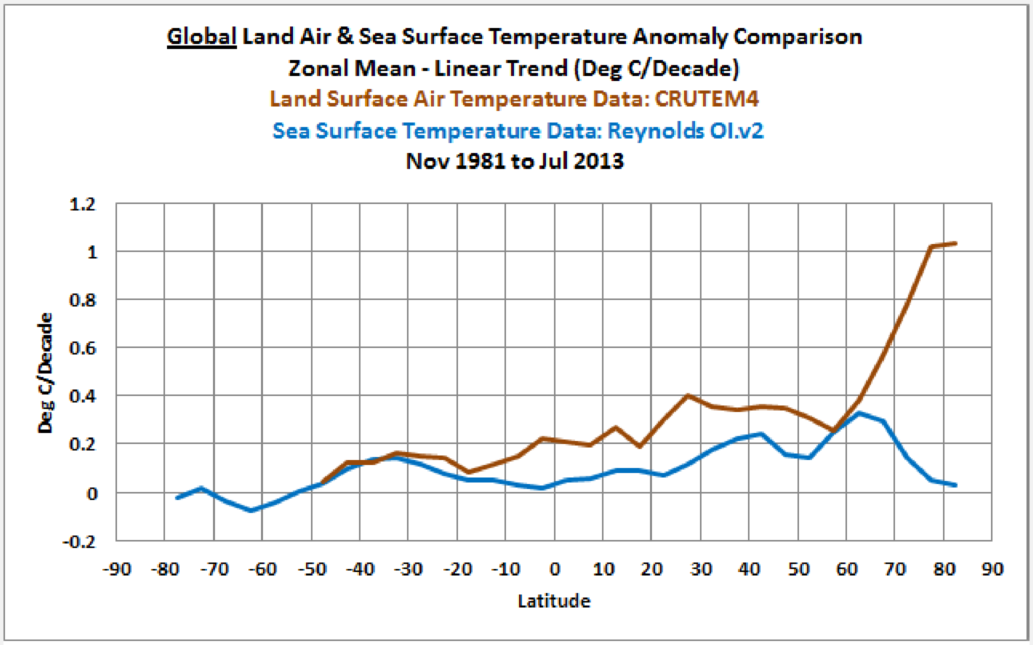


Figure 1.18-2

Note how the two datasets diverge greatly starting at about 60N. The warming rates of land surface air temperature skyrocket as they approach the North Pole, but the warming rates of the sea surface temperature data drops to almost zero.

Sea surface temperature data only exist in the polar oceans when and where the sea ice melts and there is ice-free ocean. Sea surface temperature data do not exist when sea ice is present. When and where sea ice exists, NOAA uses the freezing point of sea water for the temperatures in its Reynolds OI.v2 satellite-enhanced data (and its ERSST.v4 reconstruction as well). Then, for example, when the ice melts to a new seasonal low that exposes new areas of ice-free ocean, the measured sea surface temperatures for those new areas are compared to the freezing temperature of the sea water for anomalies. Ice-free ocean exists in the polar oceans for only part of the year. Therefore, the warming rates in the Arctic are damped by the existence of the sea ice during the other times of the year. That is, when sea ice exists, there is a zero sea surface temperature anomaly in a grid. Those “zeroes” are averaged with the actual readings, thereby damping the sea surface temperature data for the polar oceans.

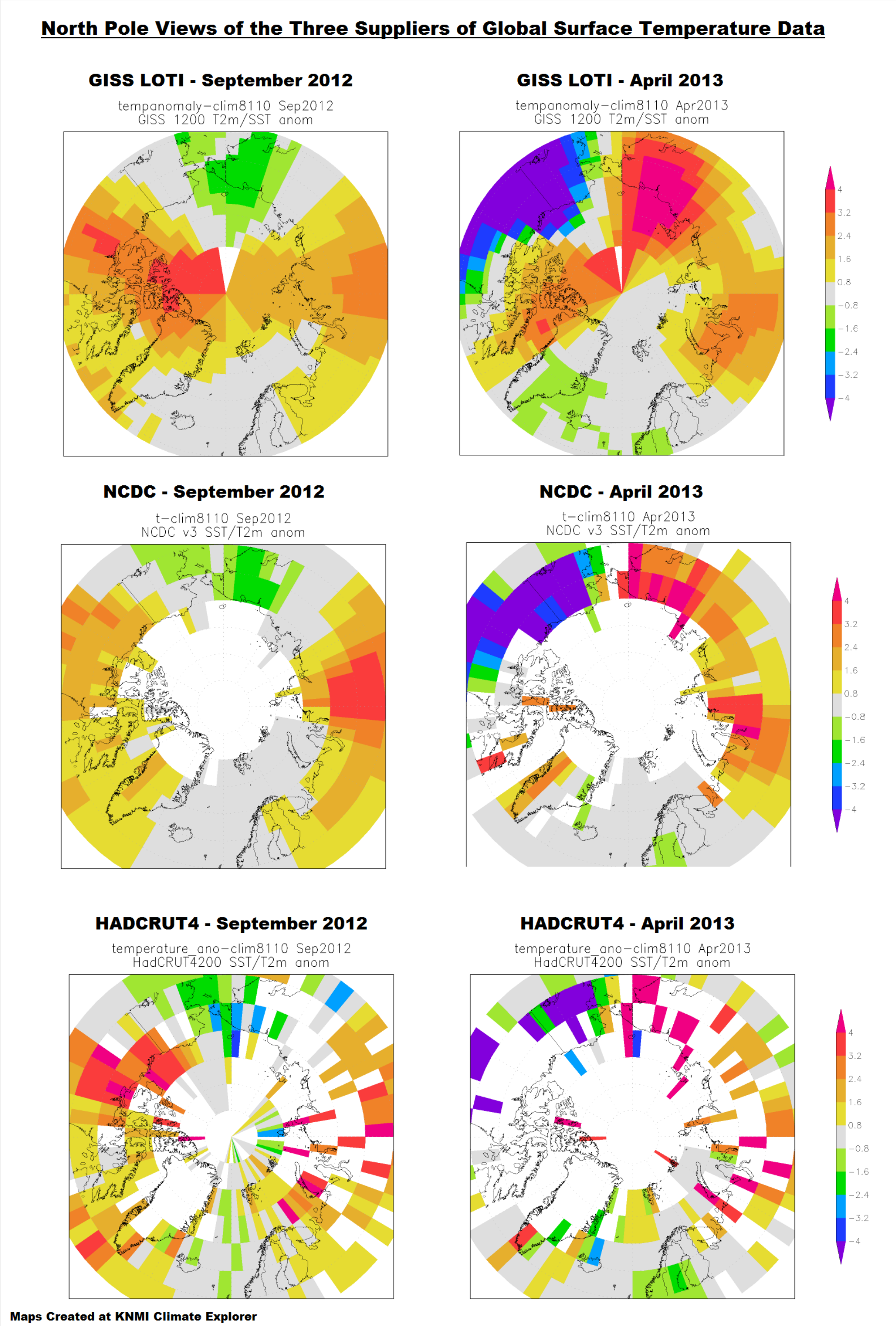

North Pole Views of the Three Suppliers of Global Surface Temperature Data
GISS LOTI - September 2012
tempanomaly–clim8110 Sep2012
GISS 1200 T2m/SST anom
GISS LOTI - April 2013
tempanomaly–clim8110 Apr2013
GISS 1200 T2m/SST anom
NCDC - September 2012
t–clim8110 Sep2012
NCDC v3 SST/T2m anom
NCDC - April 2013
t–clim8110 Apr2013
NCDC v3 SST/T2m anom
HADCRUT4 - September 2012
temperature_ano–clim8110 Sep2012
HadCRUT4200 SST/T2m anom
HADCRUT4 - April 2013
temperature_ano–clim8110 Apr2013
HadCRUT4200 SST/T2m anom
4
3.2
2.4
1.6
0.8
–0.8
–1.6
–2.4
–3.2
–4
Maps Created at KNMI Climate Explorer

Figure 1.18-3

That does not mean that polar amplification of marine air temperatures over sea ice does not exist when sea ice covers the polar oceans. Those temperatures are simply not included in land surface temperature datasets, because they occur over the oceans. And they are not included in sea surface temperature datasets, because sea surface temperature datasets do not represent marine air temperatures. Last, very little marine air temperature data exists for the polar oceans, especially when sea ice is present. We'll use Figure 1.18-3 to show how the 3 suppliers of global temperature product account for this.

GISS masks sea surface temperature data anywhere sea ice has existed since 1880 and then extends land surface air temperature anomalies out over the polar oceans. See the top two maps in Figure 1.18-3. Unfortunately, GISS does not use sea surface temperature data when it is available in the polar oceans — they continue to use land surface temperature data over the open oceans when sea ice melts seasonally. This creates a warm bias in the GISS product compared to the data from NCDC and UKMO, because the NCDC and UKMO do not use those techniques. The NCDC simply excludes data in the Arctic whenever sea ice exists to eliminate biases in either direction. See the middle maps in Figure 1.18-3 above.

To add more confusion to a complex discussion, the UKMO HADCRUT4 data is not infilled like the NODC and GISS data. That's plainly obvious in the bottom maps in Figure 1.18-3. That is, if a 5-degree longitude by 5-degree latitude grid does not have data during a given month, that grid is left blank. As a result, their sea surface temperature data in the polar oceans are not damped by the zero anomalies associated with the sea ice. That is, if sea surface temperature data is available, it is used in the UKMO HADCRUT4 data. When it's not available, the grid contains no data.

MODEL-DATA COMPARISON OF POLAR AMPLIFICATION

In the Introduction, I noted that climate models simulated polar amplification very poorly. For the next three graphs, we're using the latest version of the GISS Land-Ocean Temperature Index (the version with the NOAA pause-buster sea surface temperature data, ERSST.v4) because GISS includes data in the Arctic. And the models are represented by the multi-model mean of the climate models stored in the CMIP5 archive, which was used by the IPCC for their 5th Assessment Report (AR5). The models chosen use the historic and RCP6.0 forcings.

Let's start with the recent warming period, 1975-2014. See Figure 1.18-4. The models do a reasonable job of simulating the polar amplification during this period. One might expect that, because models are tuned to most of this period. The greatest divergence for the period of 1975-2014 occurs in the mid latitudes of the Southern Hemisphere.

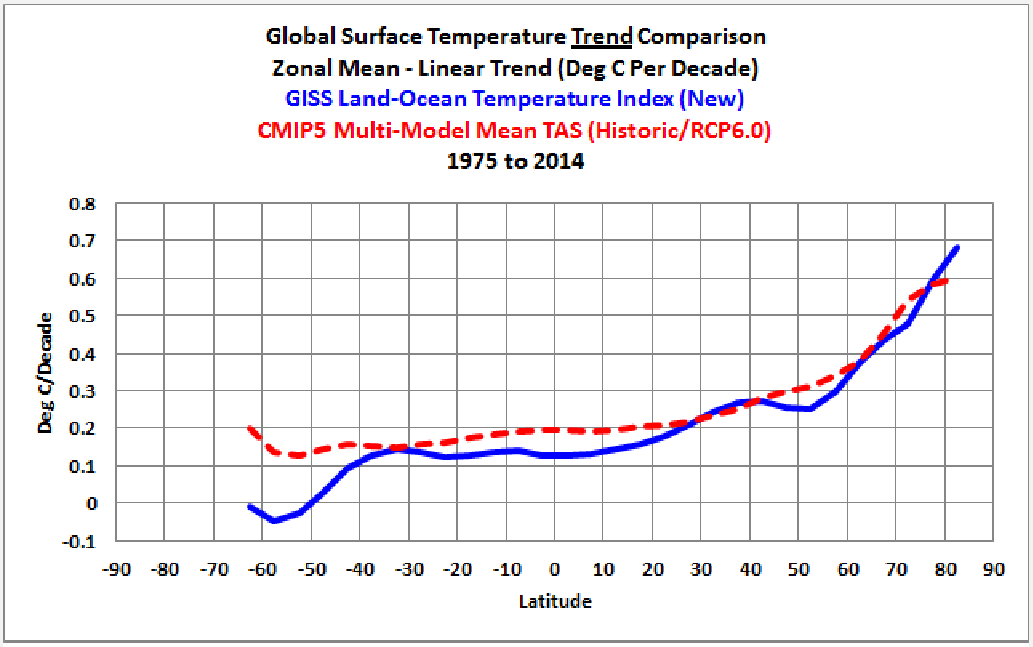


Figure 1.18-4

Note: While the climate models do a reasonable job of simulating the polar amplification that exists in the Arctic during the period of 1975-2014, they do a horrendous job of simulating the sea ice loss there. See Figure 1.18-5. While the time periods do not align exactly due to the availability of the sea ice area data, it is well known that models cannot simulate the loss of sea ice in the Arctic.

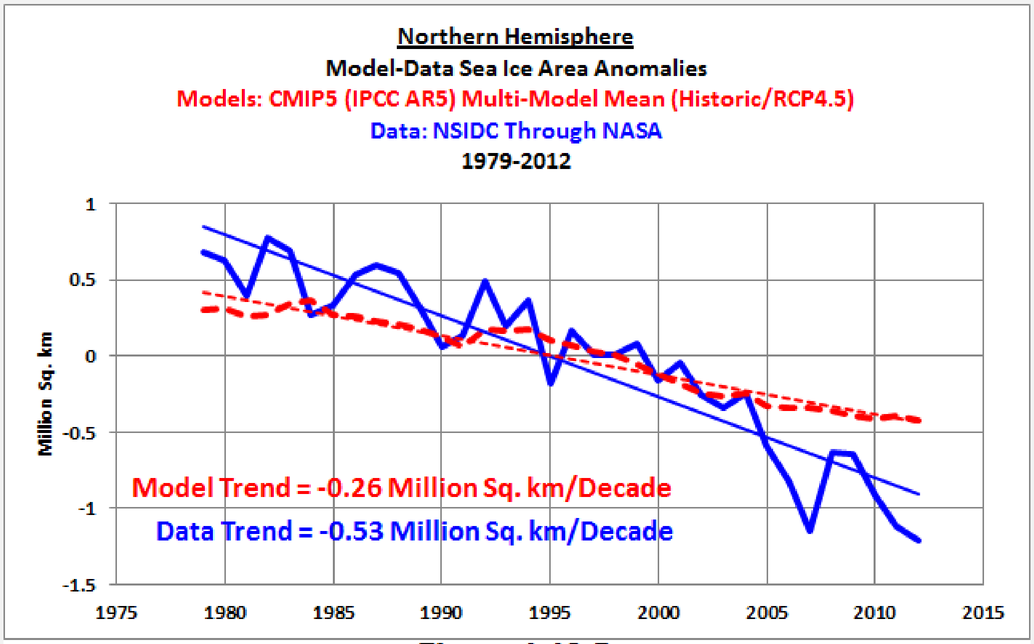


Figure 1.18-5

[End note.]

Figure 1.18-6 compares the modeled and observed warming and cooling rates on a latitude-average basis for the mid-20th Century slowdown period of 1945-1975. The models fail miserably during this time period. They fail to capture the polar amplified cooling that occurred north of 60N latitude.

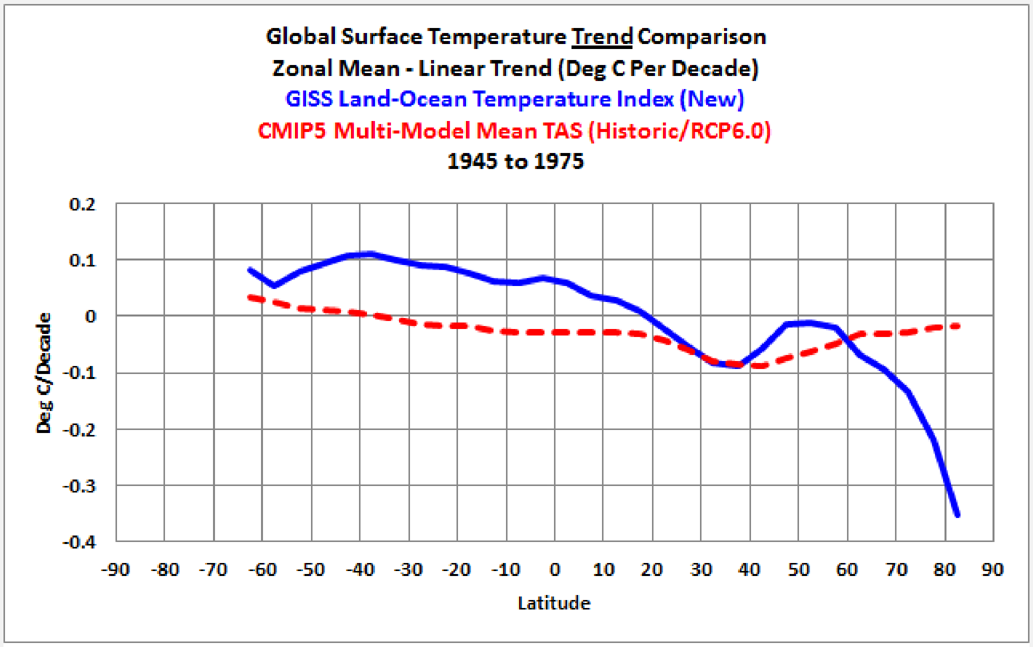


Figure 1.18-6

# # #

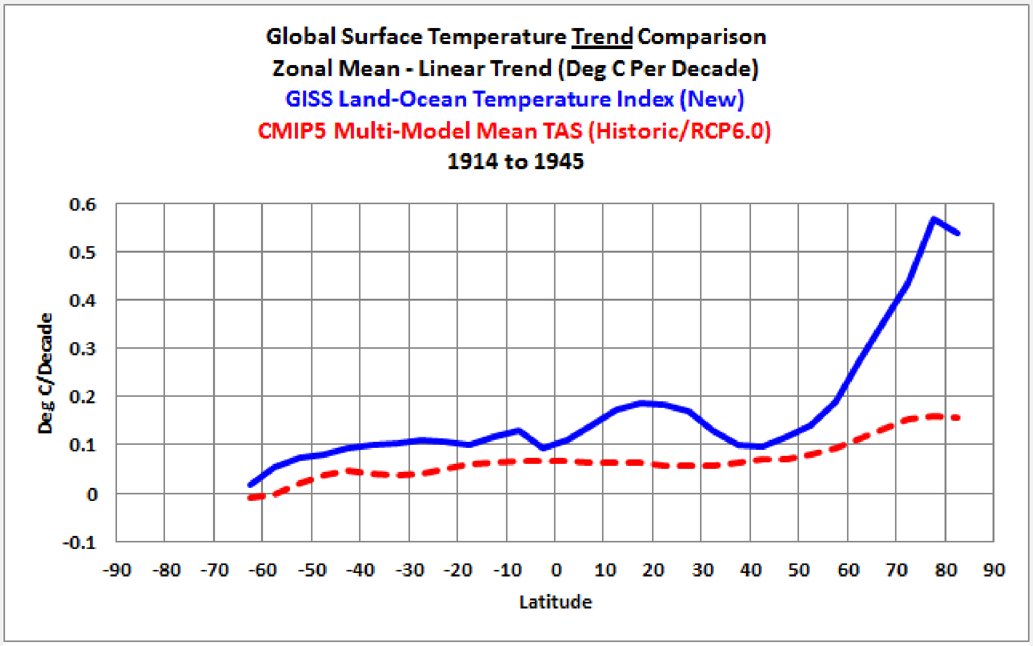


Figure 1.18-7

Last but not least is Figure 1.18-7. It shows the observed and modeled warming rates during the early warming period of 1914-1945. The models show very little polar amplification at this time, but the data indicate it was comparable to the polar amplification we've seen since 1975.

CHAPTER CLOSING

Polar amplification occurs naturally. It provides amplified cooling in the Arctic during cooling periods as well as amplified warming there during warming periods. The actual air surface temperatures in the Arctic and Southern Oceans when sea ice exists are presently not measured over the oceans. Global surface temperature suppliers address the surface air temperatures above sea ice in different ways.

Climate models have been programmed to capture the polar amplification that occurred during the recent warming period, but the models fail miserably at capturing the observed polar amplified warming from 1914 to 1945 and the observed polar amplified cooling from 1945 to 1975. Based on that poor performance, climate models have limited to no value when they're used to project how Arctic temperatures might vary in the future. That is, if climate models cannot simulate how polar amplification worked in the past, we can have no confidence in the climate model-based projections of polar amplification in the future.

1.19 – Heat Stored in the Oceans and the 2nd Law of Thermodynamics – The Heat Cannot Come Back to Haunt Us

Global surface temperatures are not warming in agreement with the rates predicted by climate models, especially the surface of the oceans. So scientists have had to look elsewhere for the missing heat. If greenhouse gases have not warmed the surface of the oceans, the logical place for the missing heat to be hiding is deeper in the oceans. Since the early 2000s, the temperature and salinity of the oceans to depths of 2000 meters (about 6600 feet) have been sampled by sensors called ARGO floats. Even with all of those sensors, the subsurface ocean data are still not able to account for all of the heat simulated by climate models. That aside…

Because of the tremendous heat capacity of the oceans, the actual change in temperature of the global oceans is minute. The annual variations in the temperature of the global oceans are measured in hundredths and thousandths of a degree Celsius. See Figure 1.19-1. Please note that it is showing the annual change in temperature, not the anomalies. For the 2004 value in this graph, we're subtracting the 2003 value from the 2004 value. Likewise, we're subtracting the 2004 value from the 2005 value to determine the 2005 value, etc., through 2014.

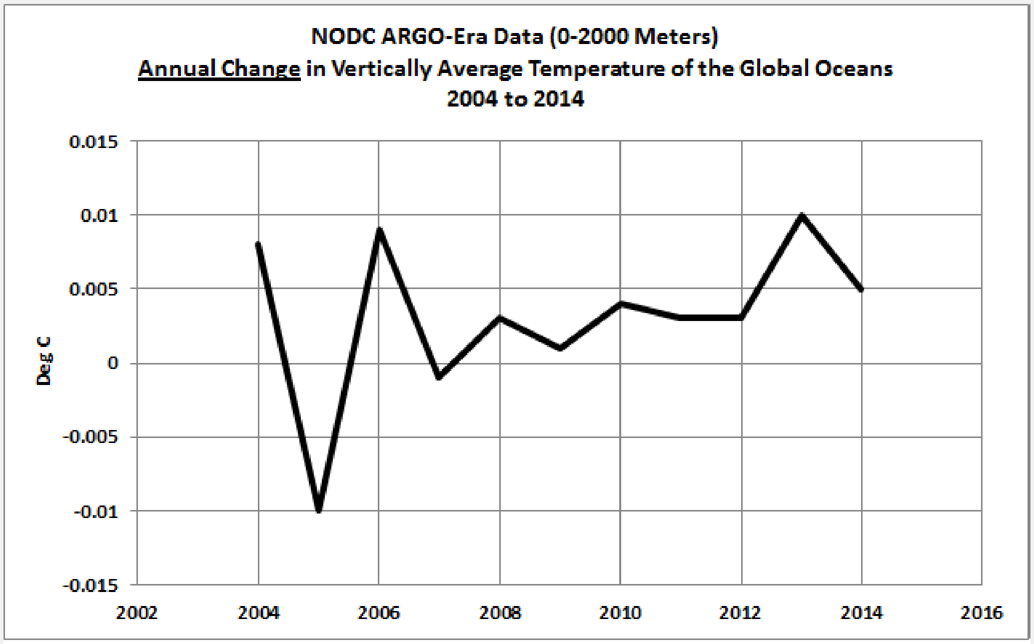


Figure 1.19-1

Alarmists have a different view of the tremendous heat capacity of the oceans. It has often been said, if the heat being stored in the global oceans were to suddenly be released into the atmosphere, the rise in atmospheric temperatures would be devastating.

It's as if the alarmists somehow think the heat is being held in a reservoir somewhere deep within the oceans, a reservoir that is isolated from the rest of the oceans, growing hotter and hotter, and that it will rise to the surface and heat the atmosphere like a volcanic eruption. That thought has no foundation is physics…or common sense.

The second law of thermodynamics basically says that heat naturally flows from an object of higher temperature to an object of lower temperature, and that heat does not flow in the opposite direction naturally. Let's think about that in the context of the oceans.

Let's assume for discussion that man-made greenhouse gases are capable of heating the ocean surface, but due to ocean processes it is not warming the surface but is being carried deep into the oceans. There are ways that could happen.

The second law of thermodynamics says the heat will flow from the water with the higher temperature to the water with lower temperature. The warmer waters that had been driven deep into the ocean will cool as the heat flows to the surrounding cooler waters, and the cooler waters surrounding it will warm. Eventually, the water temperatures would equalize. That's why alarmist claims of the heat coming back to haunt us has no basis in reality. It has established (and would simply establish in the future) a slightly warmer background state of the oceans—nothing more.

Something else to consider: the ARGO floats, after adjustments, have shown the oceans have warmed, but as shown in Figure 1.19-2, the warming has occurred in some ocean basins but not in others.

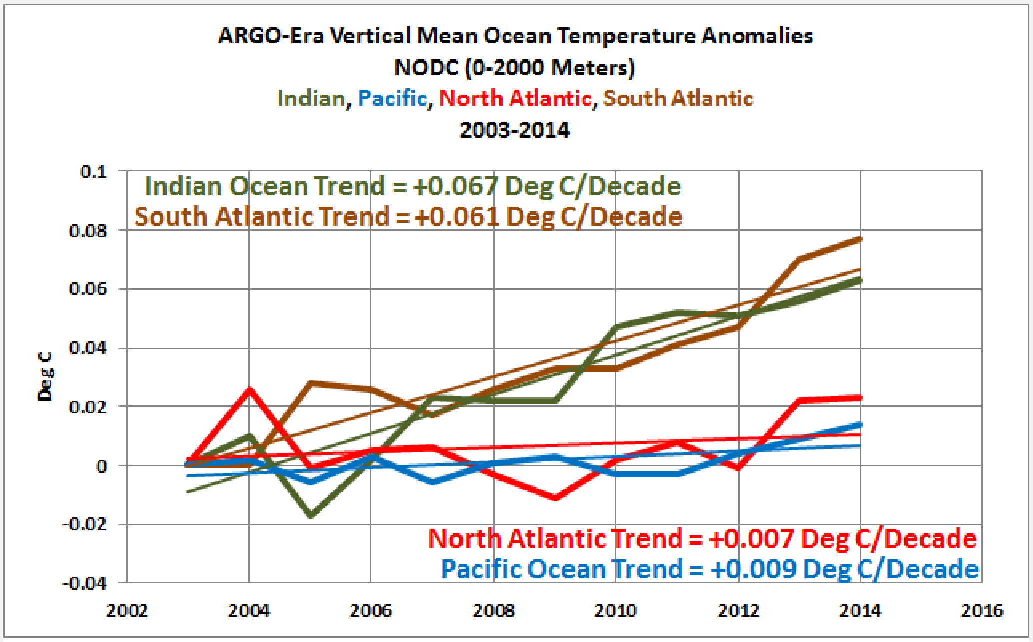
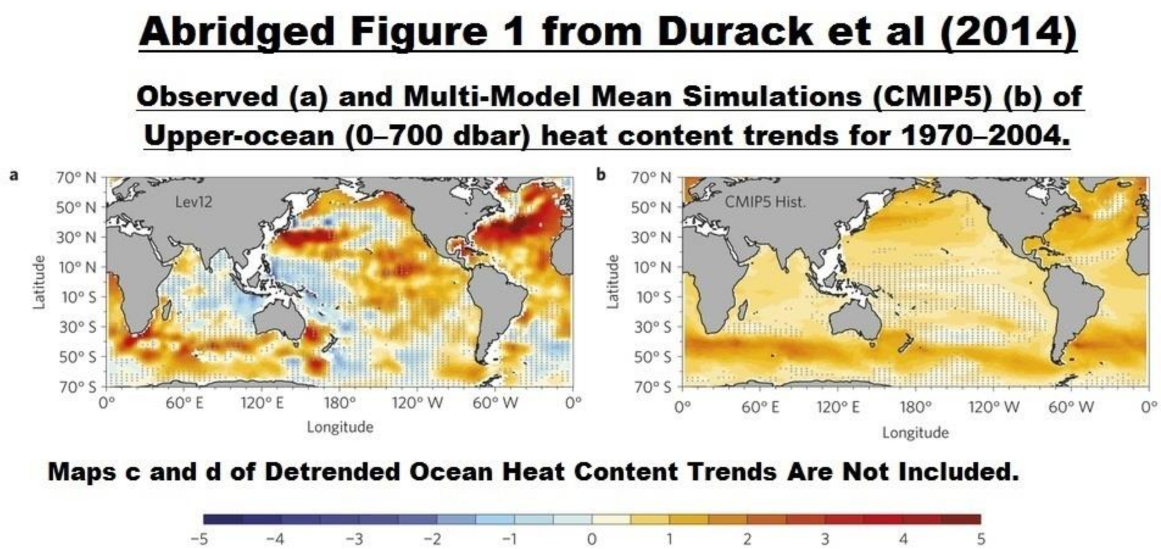


Figure 1.19-2

Greenhouse gases like carbon dioxide are said to be well-mixed, meaning that they have a lifetime in the atmosphere so that they should be mixed relatively homogeneously within the atmosphere and have a relatively equal effect globally. In fact, climate models show a relatively uniform warming across all oceans, not only at the surface but also at depth. Let me repeat a discussion from the Introduction:



a,**c**, Observations taken from Lev12 (ref. 11). **b**,**d**, MMM results taken from CMIP5 historical simulations. Lower panels (**c**,**d**) show maps with the global average trends removed. All trends are reported in units of J × 10^3 kg^{-1} 35 yr^{-1} (a value of 4 being approximately equivalent to 1 °C 35 yr^{-1} depth-averaged warming). Stippling marks regions where the four observational estimates do not agree in sign (**a**,**c**) or where >25% of the models simulate trends with a sign opposite to the MMM (**b**,**d**).

Figure 1.19-3

I had explained the difference in the warming rates between the Indian and Pacific Oceans a number of years ago. See the discussion of Figures 19 and 20 and Animations 1 and 2 in the post Is Ocean Heat Content Data All It's Stacked Up To Be? The recent paper Lee et al (2015) confirmed my discussion of the transfer of ENSO-related waters from the tropical Pacific to the Indian Ocean. But because man-made greenhouse gases are said to be evenly mixed, the multi-model mean of the climate models used by the IPCC (for attribution studies and projections of future climate) show a relatively uniform warming of the oceans, the right-hand map in Figure 1.19-3. Yet in the real world that is not the case, as shown in the left-hand map. Those maps are from Durach et al. (2014) Quantifying underestimates of long-term upper-ocean warming. Notice that it covers the period of 1970-2004. It's rare when climate modelers provide side-by-side maps of modeled and observed ocean heat content trends, so rare that I have not been able to find maps comparing models and data for the deep ocean during the ARGO era. (Quick note, the multi-model mean basically represents how the oceans should have warmed if they were warmed by man-made greenhouse gases.) Putting the lack of an ARGO-era comparison aside, it's difficult at best, therefore, to imagine how climate modelers will attempt to explain how man-made greenhouse gases could be warming one-third of the oceans to depths of more than a mile but not the other two-thirds when their models have a history of showing a more uniform warming.

WHAT ABOUT EL NIÑOS?

We've recently seen blog posts by alarmists that suggest that El Niño events are a way in which greenhouse gas-related heat is released from the oceans and later redistributed within them. The alarmists are expressing their misunderstanding of El Niño and how the warm water for El Niños is generated. We'll discuss those topics in great detail in Chapter 3.7 – Ocean Mode: El Niño and La Niña.

Further to that topic, there have been a series of climate model-based papers that claim El Niño and La Niña events will become stronger in the future. Examples:

- Cai et al. (2015) Increased frequency of extreme La Nina events under greenhouse warming
- Kim et al. (2014) Response of El Niño sea surface temperatures to greenhouse warming
- Cai et al, (2014) Increasing frequency of extreme El Nino events due to greenhouse warming

Unfortunately, climate models do not properly simulate the basic feedbacks that cause El Niño and La Niña events. Models also do not properly simulate most aspects of El Niño and La Niña. We'll discuss those model failings in Chapter 3.7.   Climate models can't even properly simulate the sea surface temperatures of the Pacific as a whole. See General Discussions 2 and 3. In other words, papers like those linked above have to be viewed as alarmist science fiction…nothing more.

1.20 – How Does the IPCC Determine Likelihoods and Confidence?

Throughout the IPCC reports you'll find the words and phrases "likely", "very likely", "extremely likely" and "virtually certain", all in italics. The other half of the spectrum includes "unlikely", "very unlikely", "extremely unlikely" and "exceptionally unlikely". Those are how the IPCC categorizes uncertainties in their reports. *Box TS.1 Treatment of Uncertainty* on page 36 of the Technical Summary (18MB .pdf) of the IPCC's 5th Assessment Report begins (my boldface):

> *Based on the Guidance Note for Lead Authors of the IPCC Fifth Assessment Report on Consistent Treatment of Uncertainties, this WGI Technical Summary and the WGI Summary for Policymakers rely on two metrics for communicating the degree of certainty in key findings, which is based on author teams' evaluations of underlying scientific understanding:*
>
> - *Confidence in the validity of a finding, based on the type, amount, quality and consistency of evidence (e.g., mechanistic understanding, theory, data, models, **expert judgement**) and the degree of agreement. Confidence is expressed qualitatively.*
> - *Quantified measures of uncertainty in a finding expressed probabilistically (based on statistical analysis of observations or model results, or **expert judgement**).*

Expert judgment is, of course, subjective. Unfortunately, the report does not identify whether the confidences and uncertainties of specific findings were determined through analysis or through "expert judgement".

A further discussion with clarifications can be found in the IPCC's July 2010 Guidance Note for Lead Authors of the IPCC Fifth Assessment Report on Consistent Treatment of Uncertainties.

Dr. Judith Curry of the Georgia Institute of Technology wrote in her blog post 95%(?):

> *Yesterday, a reporter asked me how the IPCC came up with the 95% number. Here is the exchange that I had with him:*
>
> ***Reporter:*** *I'm hoping you can answer a question about the upcoming IPCC report. When the report states that scientists are "95 percent certain" that human activities are largely to cause for global warming, what does that mean? How is 95 percent calculated? What is the basis for it? And if the certainty rate has risen from 90 n 2007 to 95 percent now, does that mean that the likelihood of*

> *something is greater? Or that scientists are just more certain? And is there a difference?*
> .
> ***JC:*** *The 95% is basically expert judgment, it is a negotiated figure among the authors. The increase from 90-95% means that they are more certain. How they can justify this is beyond me.*
> .
> ***Reporter:*** *You mean they sit around and say, "How certain are you?" "Oh, I feel about 95 percent certain. Michael over there at Penn State feels a little more certain. And Judy at Georgia Tech feels a little less. So, yeah, overall I'd say we're about 95 percent certain." Please tell me it's more rigorous than that.*
> .
> ***JC:*** *Well I wasn't in the room, but last report they said 90%, and perhaps they felt it was appropriate or politic that they show progress and up it to 95%.*
> .
> ***Reporter:*** *So it really is as subjective as that?*
> .
> ***JC:*** *As far as I know, this is what goes on. All this has never been documented.*

The reporter appears to be Andrew Orlowski, because his article IPCC: Yes, humans are definitely behind all this global warming we aren't having at TheRegister.co.uk includes part of that discussion with Dr. Curry. Orlowski's article closes with a quote that is noteworthy:

> *At the IPCC press conference today, Professor Thomas Stocker, co-chair of WG1, told press that "we're confident because we're confident".*

That sounds scientific, now, doesn't it?

1.21 – Are there Symptoms of Human-Induced Global Warming and Climate Change?

Proponents of the hypothesis of human-induced global warming and climate change will often present data as evidence that mankind has altered climate on Earth. The other line of evidence presented by the Intergovernmental Panel on Climate Change (IPCC) has been climate models. But are those data and models actually evidence of man-made global warming and climate change? In this chapter we'll discuss a number of topics:

- Measured Atmospheric Carbon Dioxide Levels
- Climate Models
- Temperature-Based Data
- Glaciers, Ice Sheets and Sea Levels
- Miscellaneous, Including Arctic sea ice, Heat Waves, Cold Spells and Northern Hemisphere snow cover

MEASURED ATMOSPHERIC CARBON DIOXIDE LEVELS HAVE INCREASED

Atmospheric carbon dioxide has been measured at the Mauna Loa observatory in Hawaii since the late 1950s, a result of the research efforts of Charles David Keeling of the Scripps Oceanographic Institute. These measurements have resulted in a graph that is widely known as "the Keeling Curve". See Figure 1.21-1. Data show CO_2 levels in the atmosphere have increased.

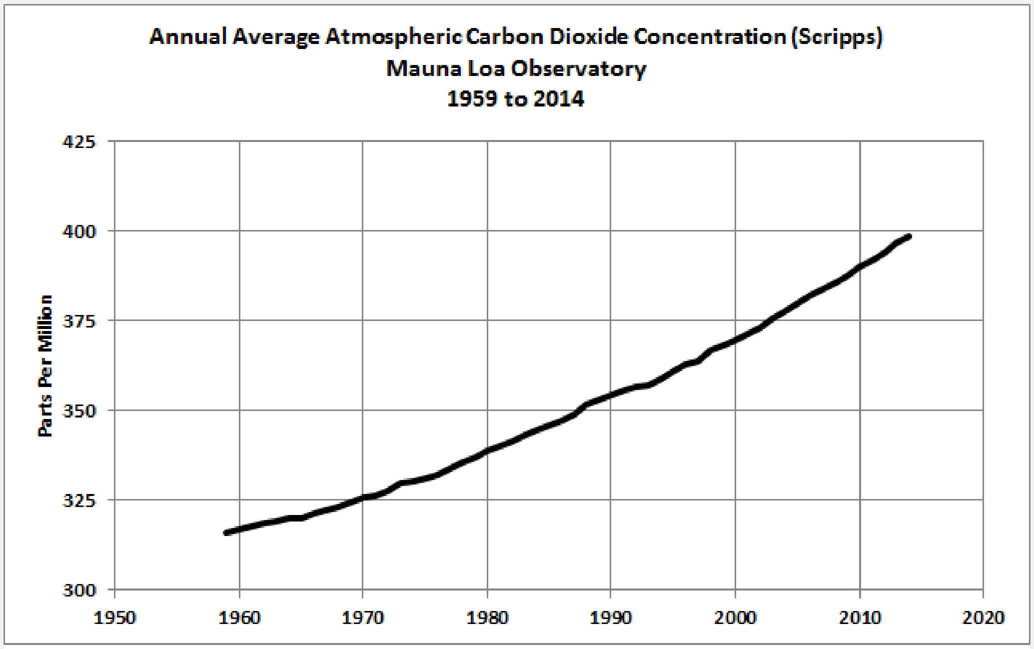


Figure 1.21-1

NOTE: Weekly Mauna Loa CO_2 concentration data are available since 1974 through a link at the NOAA Earth System Research Laboratory (ESRL) data page here, and monthly data from 1958 should be available through links at the ESRL data page here. Unfortunately, the ESRL links to the monthly data were not operational at the time of this writing, so I relied on the data available through the Monthly Climate Indices webpage at the KNMI Climate Explorer. [End note.]

Numerous lines of evidence indicate that the measured increase in atmospheric concentration of CO_2 can only be explained through increased emissions of greenhouse gases caused by the burning of fossil fuels. But is the measured increase in CO_2 concentration proof that it is responsible for the global warming experienced in that time?

No.

CO_2 data only provide evidence that CO_2 levels have increased. Nothing more, nothing less. While those increases in atmospheric levels of CO_2 hypothetically should cause global warming, it is unknown whether they are in fact responsible for increased surface and atmospheric temperatures and ocean heat uptake during that time. Climate models still cannot simulate the naturally occurring processes that can cause the warming of the oceans (at the surface and at depth) over decadal and multidecadal periods.

CLIMATE MODELS CAN ONLY SIMULATE THE OBSERVED GLOBAL WARMING WHEN THEY ARE FORCED BY MAN-MADE GREENHOUSE GASES

The IPCC has been using this failed argument for many years. We discussed this in Chapter 1.12. Figure 1.21-2 is the same as Figure 1.12-2 from that chapter. It compares the outputs of climate models that are driven with only natural forcings to the outputs of climate models driven by natural AND man-made forcings. As shown, only climate models forced by both natural and man-made factors can create the warming in the latter part of the 20th Century.

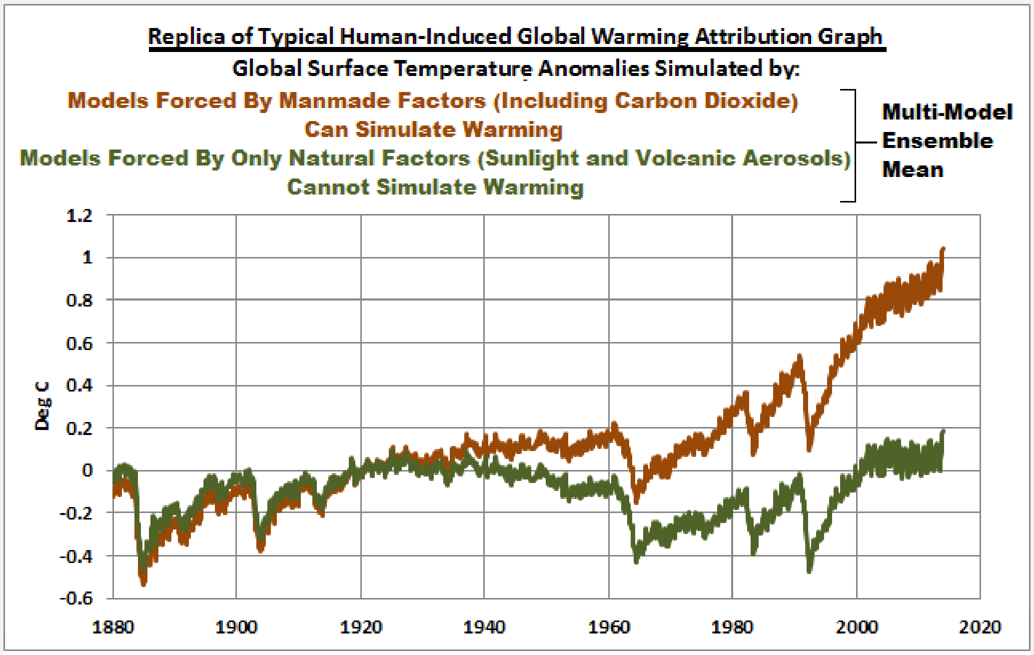


Figure 1.21-2

There are other examples of the IPCC's illustration of models using natural and man-made forcings versus natural forcings only. One was presented as their Figure SPM.6 in the Summary for Policymakers of the IPCC's 5th Assessment Report. See my Figure 1.21-3. In it, the IPCC has included cartoon-like graphs of regional surface temperature and ocean heat content, modeled and observed. (See the note at the end of this chapter for the citation required by the IPCC for the use of their image.)

The logic behind those graphs is simplistic, almost childish. The models that include anthropogenic and natural forcings can simulate the observed warming, but the models that include only natural forcings cannot simulate it; therefore, the anthropogenic forcings must be responsible for the observed global warming.

Figure SPM.6 from the IPCC's 5th Assessment Report

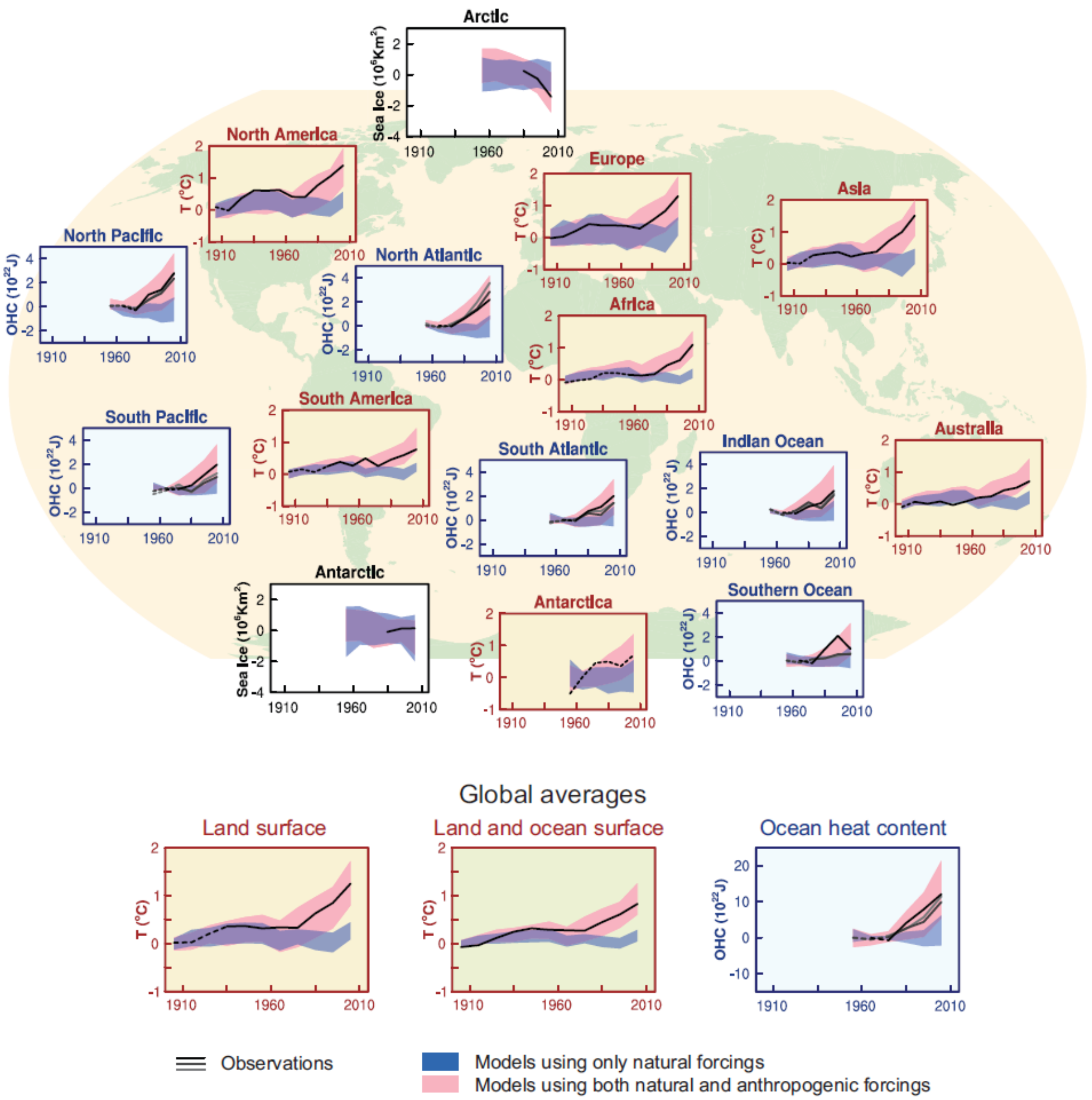


Figure SPM.6 | Comparison of observed and simulated climate change based on three large-scale indicators in the atmosphere, the cryosphere and the ocean: change in continental land surface air temperatures (yellow panels), Arctic and Antarctic September sea ice extent (white panels), and upper ocean heat content in the major ocean basins (blue panels). Global average changes are also given. Anomalies are given relative to 1880–1919 for surface temperatures, 1960–1980 for ocean heat content and 1979–1999 for sea ice. All time-series are decadal averages, plotted at the centre of the decade. For temperature panels, observations are dashed lines if the spatial coverage of areas being examined is below 50%. For ocean heat content and sea ice panels the solid line is where the coverage of data is good and higher in quality, and the dashed line is where the data coverage is only adequate, and thus, uncertainty is larger. Model results shown are Coupled Model Intercomparison Project Phase 5 (CMIP5) multi-model ensemble ranges, with shaded bands indicating the 5 to 95% confidence intervals. For further technical details, including region definitions see the Technical Summary Supplementary Material. {Figure 10.21; Figure TS.12}

Figure 1.21-3

Why is the logic flawed? There are numerous interrelated reasons: (1) It is well known that there are naturally occurring ocean-atmosphere processes that than enhance or suppress global warming over decadal and multidecadal periods. As examples, these include phenomena known as El Niño events and the Atlantic Multidecadal Oscillation, both of which we will discuss in detail in Section 3. (2) It is also well known that climate models used for simulations of past climate and for long-term projections of future global warming cannot simulate those naturally occurring ocean-atmosphere processes that enhance or suppress global warming over decadal and multidecadal periods. One reason we know this is climate models can't simulate the warming that took place during the early to mid-20th Century. See Figure 1.21-4. I presented the same graphs in Chapter 1.17. Let's repeat that discussion because it's very important.

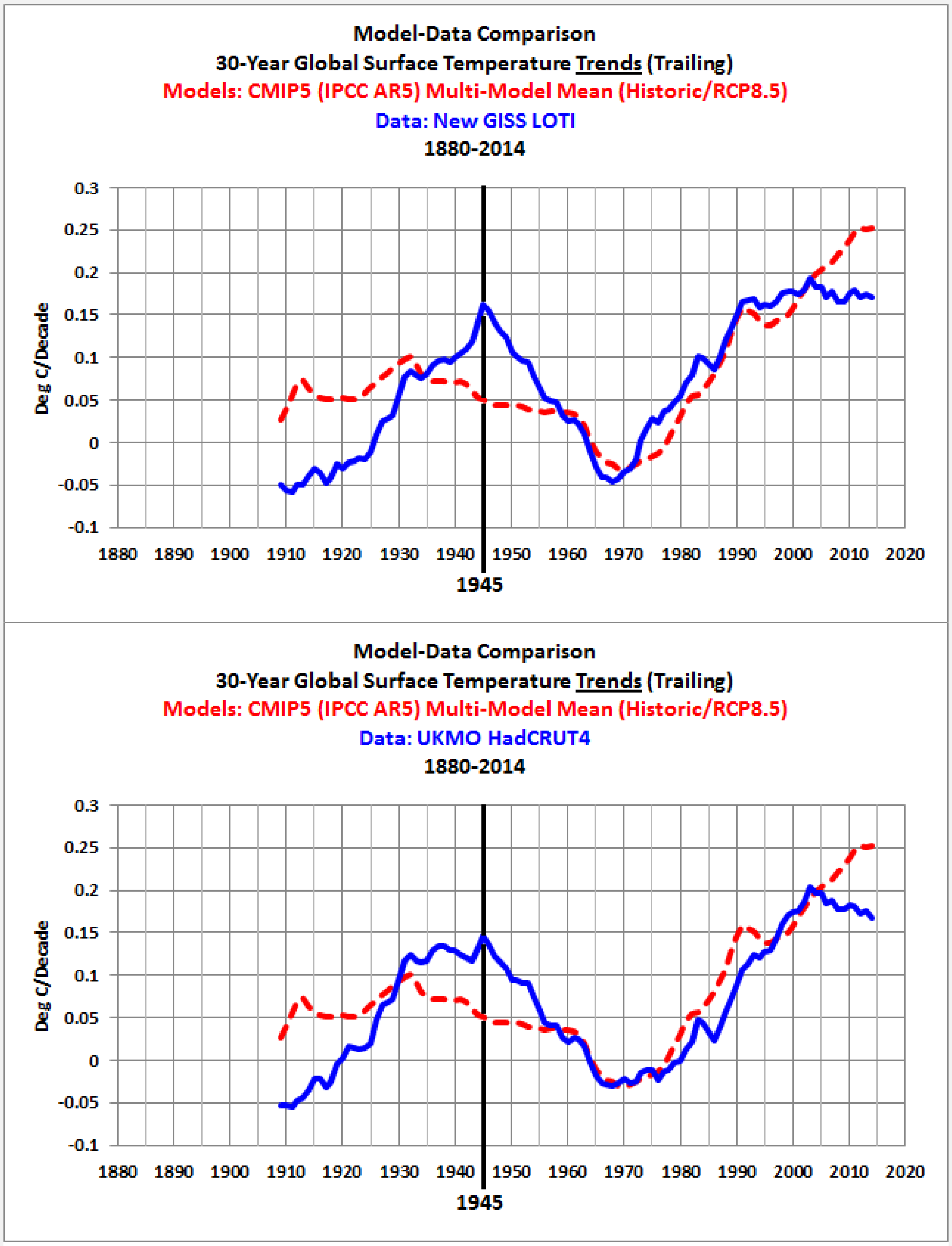


Figure 1.21-4

Figure 1.21-4 contains two model-data comparisons of 30-year trends (trailing) in global surface temperatures. The models in both graphs are represented by the multi-model mean of the climate models stored in the CMIP5 archive, which were used by the IPCC for their 5th Assessment Report. The model outputs are available through the KNMI Climate Explorer. For the data, the top graph includes the GISS Land-Ocean Temperature Index (LOTI), while the bottom graph includes the HadCRUT4 reconstruction from the UKMO.

An explanation of what's being presented in Figure 1.21-4: The final data points are the 30-year trends in deg C/decade for the period of 1985-2014, the data points immediately before it show the linear trends from 1984-2013, etc., working back in time until the first data points at 1909, which show the 30-year linear trends from 1880-1909. I've used the term *Trailing* to signify that the trends are shown at last years the 30-year periods.

I've highlighted the year 1945 in both graphs. With both the GISS LOTI and UKMO HadCRUT4 global surface temperature reconstructions, the warming rates (the linear trends) for the early warming period both peak at the 30-year period ending in 1945. And the two 30-year trends are roughly the same at about 0.15 deg C/decade. On the other hand, the model mean (the consensus or groupthink of the modeling groups) show global surface temperatures should only have warmed about 0.05 deg C/decade for that 30-year period ending in 1945, if global warming was only driven by the greenhouse gases and other factors that are used to force the models.

In other words, Figure 1.21-4 indicates that global surface temperatures are capable of warming naturally at rates that are about 3 times faster than hindcast by the climate models. That raises a very important question: how much of the warming during the recent warming period is also natural? The fact that the models better align with the data during this period doesn't mean the surface temperatures were forced to warm at the same rates as the models. Surface temperatures have already shown they are capable or warming at rates that are 3-times higher than the models. The better alignment of models and data in recent decades simply indicates the models are tuned to simulate the warming then.

Figure 1.21-4 also suggests that climate model projections of future global warming are at about two-times too high.

In summary, because climate models cannot simulate naturally occurring coupled ocean-atmosphere processes that enhance or suppress global warming, they have no value when attempting to attribute global warming to mankind…or when attempting to predict how climate may change in the future based on projections of future CO_2 emissions.

TEMPERATURE-BASED DATA INDICATE EARTH'S SURFACE AND LOWER ATMOSPHERE HAVE WARMED AND OCEANS HAVE ACCUMULATED HEAT

Surface temperature datasets indicate Earth's surfaces have warmed since the mid to late 1800s. Satellite-based lower troposphere and mid-troposphere temperature datasets show the lower levels of the atmosphere have also warmed since the late 1970s. And ocean heat content datasets show that the oceans have accumulated heat since the mid-1950s. We'll discuss those datasets in detail in Section 4.

Do those data provide evidence that the emissions of anthropogenic greenhouse gases are responsible for that warming?

No.

The data only show that Earth's surfaces and lower levels of the atmosphere have warmed and that the oceans have accumulated heat. They show nothing more than that.

The only way the climate science community can try to attribute the warming to anthropogenic greenhouse gases is with climate models. Sadly, after decades of climate modeling efforts, climate models are not capable of simulating naturally occurring processes that can cause the oceans to accumulate heat and Earth's surfaces to warm, or stop that accumulation. The differences between reality (the data) and the virtual reality of the models (represented by the model mean) stand out quite plainly in the two graphs above in Figure 1.21-4. As a result of those failings, climate models cannot realistically be used for attribution studies. In other words, climate models are not yet fit for their intended purposes.

As you will see throughout in this book, the only real value climate models have is to show how poorly they simulate surface temperatures, sea ice extent and precipitation.

GLACIERS AND ICE SHEETS HAVE RETREATED AND SEA LEVELS HAVE RISEN

The climate science community, politicians and other advocates of human-induced climate change often present rising sea levels and retreating glaciers and ice sheets as proof of anthropogenic CO_2-driven global warming. Those are foolish lines of evidence.

Glaciers and ice sheets have been melting since the end of the last ice age, providing the mass contribution to rising sea levels. Global surface temperatures have been above the threshold necessary to cause a decrease in glacier and ice sheet mass for 10,000 years. Sadly, glaciers and ice sheets will continue to retreat and sea levels will continue to rise until global surface temperatures fall at the onset of the next ice age. As noted in the Introduction, we unfortunately, out of need, have built cities and towns within the "glacial-interglacial tidal range". Trying to hold back the "tides" of naturally rising sea levels by limiting greenhouse gas emissions only gives hope to the extremely gullible. Further to that discussion, glaciers have provided a source of water to many regions of the world, but, unfortunately, contributions to water supplies from some glaciers will eventually come to an end…and for some locations it will happen sooner than later. Windmills and solar arrays are not going to stop it.

MISCELLANEOUS

There are a number of other items comically presented by advocates as proof of man-made global warming and climate change. They include:

- Declining Arctic sea ice
- Increases in Heat Waves
- Decreases in Cold Spells
- Decreased Northern Hemisphere snow cover

We would expect those changes in a warming world, regardless of the cause of the warming. That is, in a naturally warming world, we would also expect:

- Arctic sea ice to decline,
- increases in heat waves,
- decreases in cold spells,
- and less snow cover in the Northern Hemisphere.

The facts that those things have been happening recently are not proof that the emissions of anthropogenic greenhouse gases are responsible for them.

CLOSING TO CHAPTER

Data do not prove the hypothesis of human-induced global warming. Data only represent the changes in the metric being measured. Data cannot tell us that anthropogenic greenhouse gases are causing the changes.

Unfortunately, under the direction of the IPCC and the politicians that fund climate science, the climate science community is realistically no closer to being able to attribute recent global warming and climate change to human activity than they were when the IPCC was founded back in 1988. The simple reason for this failure is how the IPCC defines its role. As noted in the Introduction, we can find their role at IPCC's History webpage. They state (my boldface and caps):

> *Today the IPCC's role is as defined in Principles Governing IPCC Work, "...to assess on a comprehensive, objective, open and transparent basis the scientific, technical and socio-economic information relevant to* ***understanding the***

> ***scientific basis of risk of HUMAN-INDUCED climate change****, its potential impacts and options for adaptation and mitigation.*

The primary problem obviously is the fact that the IPCC has focused all of their efforts on “understanding the scientific basis of risk of **human-induced** climate change”. The IPCC has never realistically tried to determine if natural factors could have caused most of the warming the Earth has experienced over the past century. For decades, they’ve ignored everything other than the possible impacts of man-made greenhouse gases. The role of the IPCC has always been to prepare reports that support a political agenda: the reduction of greenhouse gas emissions caused by the burning of fossil fuels. As a result, that’s where all of the research money went. In the two plus decades since the founding of the IPCC, taxpayers around the globe have invested tens of billions of dollars in climate models and studies of those climate models, which sadly are simulating virtual-reality planets that bear no relationship to the one we inhabit.

NOTE

The following citation is required by the IPCC for the use of their Figure SPM.6:

IPCC, 2013: Summary for Policymakers. In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1–30, doi:10.1017/CBO9781107415324.004

1.22 – What are Global Brightening and Global Dimming?

Global brightening refers to an increase in the amount of sunlight reaching the Earth's surface. Conversely, there are also discussions of global dimming over certain time periods.

There are a number of studies that show the Earth has experienced a sizeable increase in the amount of sunlight reaching Earth's surface since the late-1970s, early-1980s. That increase is said to be caused by decreases in cloud cover and sun-blocking aerosols. For example, there's Wild et al. (2005) From Dimming to Brightening: Decadal Changes in Solar Radiation at Earth's Surface. Its abstract reads (my boldface):

> *Variations in solar radiation incident at Earth's surface profoundly affect the human and terrestrial environment.* ***A decline in solar radiation at land surfaces has become apparent in many observational records up to 1990, a phenomenon known as global dimming. Newly available surface observations from 1990 to the present, primarily from the Northern Hemisphere, show that the dimming did not persist into the 1990s. Instead, a widespread brightening has been observed since the late 1980s.*** *This reversal is reconcilable with changes in cloudiness and atmospheric transmission and may substantially affect surface climate, the hydrological cycle, glaciers, and ecosystems.*

And there's Pinker et al. (2005) Do Satellites Detect Trends in Surface Solar Radiation? The abstract of Pinker et al. (2005) provides an estimate of that increase (my boldface):

> *Long-term variations in solar radiation at Earth's surface (S) can affect our climate, the hydrological cycle, plant photosynthesis, and solar power. Sustained decreases in S have been widely reported from about the year 1960 to 1990. Here we present an estimate of global temporal variations in S by using the longest available satellite record.* ***We observed an overall increase in S from 1983 to 2001 at a rate of 0.16 watts per square meter (0.10%) per year****; this change is a combination of a decrease until about 1990, followed by a sustained increase. The global-scale findings are consistent with recent independent satellite observations but differ in sign and magnitude from previously reported ground observations. Unlike ground stations, satellites can uniformly sample the entire globe.*

So, according to Pinker et al. (2005) over those 19 years, solar radiation reaching the Earth's surface (also known as downward shortwave radiation at the surface) would have increased about 3 watts/m^2 (0.16 watts/m^2/year times 19 years).

And what was the forcing from man-made greenhouse gases over that time period?

For that we can refer to the NOAA Annual Greenhouse Gas Index. See Figure 1.22-1. Note that I've zeroed the total radiative greenhouse gas forcing and that of carbon dioxide at 1983 for ease of illustration. The total increase in radiative forcing from man-made greenhouse gases (red curve) was only 0.63 watts/m^2 from 1983 to 2001, or only about 21% of the radiative forcing from global brightening, while the total increase in radiative forcing (orange curve) was only 0.42 watts/m^2 from 1983 to 2001, which is only about 14% of that from global brightening.

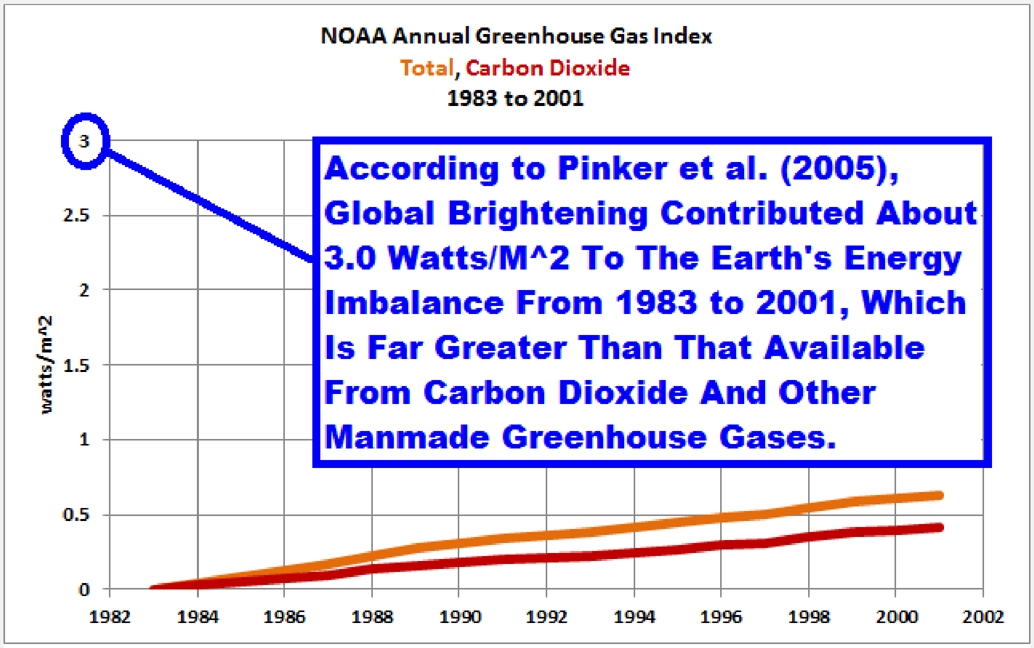


Figure 1.22-1

Now consider the oceans, where, once again, infrared radiation from man-made greenhouse gases can only penetrate the top few millimeters of the ocean surface. On the other hand, sunlight can penetrate to depths of about 300 meters, though most is absorbed in the top 10 meters.

If Pinker et al. (2005) are correct, then the primary cause of surface and ocean warming from 1983 to 2001 has to be global brightening…by far.

1.23 – Notes about Albedo

The term albedo appears a number of times in this book. Albedo is Latin for whiteness. The glossary webpage for albedo from the Earth and Space Research website includes the standard definition, with a few examples:

Albedo is the fraction of solar energy (shortwave radiation) reflected from the Earth back into space. It is a measure of the reflectivity of the earth's surface. Ice, especially with snow on top of it, has a high albedo: most sunlight hitting the surface bounces back towards space. Water is much more absorbent and less reflective. So, if there is a lot of water, more solar radiation is absorbed by the ocean than when ice dominates.

Keep in mind that the atmosphere is transparent to sunlight. That is, sunlight is not absorbed by the atmosphere. If sunlight reaches the surface of the Earth and is reflected back to space by a surface with a high albedo, the reflected portion has not played any role in warming Earth's surface.

Albedo is expressed as a decimal between zero (0.0) and one (1.0). For examples, the following discussion is based on the values listed at the Miami University (Ohio) webpage here. Values vary slightly from website to website.

Freshly fallen snow has an albedo of 0.80 to 0.95, meaning it reflects 80 to 95% of the solar energy that reaches its surface. On the other hand, a coniferous forest has an albedo that ranges from 0.10 to 0.15, and that means that a coniferous forest reflects only 10 to 15 % of the sunlight that reaches it, which also means that it absorbs about 85 to 90% of the sunlight.

According to Table 3 of Coakley (2003) Reflectance and Albedo, Surface, the oceans have the lowest albedo, approximately 0.07. Logically, because the oceans cover more of the Southern Hemisphere than the Northern Hemisphere, the albedo is lower in the Southern Hemisphere. That is, Earth's surface albedo is hemispherically asymmetrical.

CLOUDS REGULATE HEMISPHERIC ALBEDO

Of course, clouds also impact Earth's albedo, by reflecting sunlight back to space before it can reach the surface. In fact, clouds play an important role in regulating hemispheric albedo. As noted above, there is more land in the northern hemisphere than in the southern and, logically, in turn, the oceans cover more of the southern hemisphere than they do the northern. As a result, the surface albedos in the hemispheres are different.

Stephens et al. (2014) The albedo of Earth found that clouds maintain the hemispheric albedo so that it's basically the same in both hemispheres. Their abstract begins:

> *The fraction of the incoming solar energy scattered by Earth back to space is referred to as the planetary albedo. This reflected energy is a fundamental component of the Earth's energy balance, and the processes that govern its magnitude, distribution, and variability shape Earth's climate and climate change. We review our understanding of Earth's albedo as it has progressed to the current time and provide a global perspective of our understanding of the processes that define it. Joint analyses of surface solar flux data that are a complicated mix of measurements and model calculations with top-of-atmosphere (TOA) flux measurements from current orbiting satellites yield a number of surprising results including (i) the Northern and Southern Hemispheres (NH, SH) reflect the same amount of sunlight within ~ 0.2Wm^{-2}. This symmetry is achieved by increased reflection from SH clouds offsetting precisely the greater reflection from the NH land masses. (ii) The albedo of Earth appears to be highly buffered on hemispheric and global scales as highlighted by both the hemispheric symmetry and a remarkably small interannual variability of reflected solar flux (~0.2% of the annual mean flux).* ***We show how clouds provide the necessary degrees of freedom to modulate the Earth's albedo setting the hemispheric symmetry.***

It's interesting that nature has created a means (differences in cloud cover) through which Earth's albedo is maintained the same in both hemispheres.

CLIMATE MODELS DO NOT SIMULATE EARTH'S ALBEDO PROPERLY

Unfortunately, climate models stored in the CMIP5 archive (used by the IPCC for their 5th Assessment Report) do not simulate that hemispheric albedo symmetry. Continued from above, the abstract of Stephens et al. (2014) ends:

> *We also show that current climate models lack this same degree of hemispheric symmetry and regulation by clouds. The relevance of this hemispheric symmetry to the heat transport across the equator is discussed.*

Further to this climate model failing, the closing summary of Stephens et al. (2014) reads (my boldface):

> *It is also shown how the ability of present-day models of climate in simulating the statistical properties of the energy reflected from Earth varies depending upon the metric used.* ***Models fail*** *to reproduce the observed annual cycle in all components of the albedo with any realism, although they broadly capture the correct proportions of surface and atmospheric contributions to the TOA albedo.*

> *A **high model bias of albedo** has also persisted since the time of CMIP3, mostly during the boreal summer season. Perhaps more importantly, **models fail** to produce the same degree of interannual constraint on the albedo variability nor do they reproduce the same degree of hemispheric symmetry. **The significance of these shortcomings is not yet fully known, but model studies of hypothetical slab-ocean worlds suggest that interhemispheric changes in albedo can grossly affect the climate states of those worlds, shifting the ITCZ [Voigt et al., 2013, 2014; Frierson and Hwang, 2012] and altering the amount of heat moved poleward [e.g., Enterton and Marshall, 2010].***

As you'll recall, Dr. Judith Curry is Professor and Chair of the School of Earth and Atmospheric Sciences at the Georgia Institute of Technology. Dr. Curry also has a climate-related blog called Climate Etc. Her blog post The albedo of Earth was about Stephens et al. (2014). The following are her concluding remarks:

> *The implications of this paper strike me as profound. Planetary albedo is a fundamental element of the Earth's climate. This paper implies the presence of a stabilizing feedback between atmosphere/ocean circulations, clouds and radiation. Climate models do not capture this stabilizing feedback.*
>
> *The results of this paper also have interesting implications for ice ages, whereby the forcing that is predominant in one hemisphere is felt in the other.*
>
> *The failure of models to reproduce this hemisphere synchronicity raises interesting implications regarding the fidelity of climate model-derived sensitivity to CO_2.*

Once again, it is shown that the climate models used by the IPCC are not capable of simulating climate as it exists on Earth.

1.24 – A Rough Calculation of the Amount of Missing Heat…A Critical Issue

If you're new to the topic of global warming, you may think discussions of *The Missing Heat* have to do with the slowdown in global surface warming since the late 1990s, which wasn't anticipated by climate modeling groups. The term Missing Heat, however, is not related to the slowdown in global surface warming. Missing Heat is used in discussions of the heat being stored in the depths of the oceans.

OVERVIEW

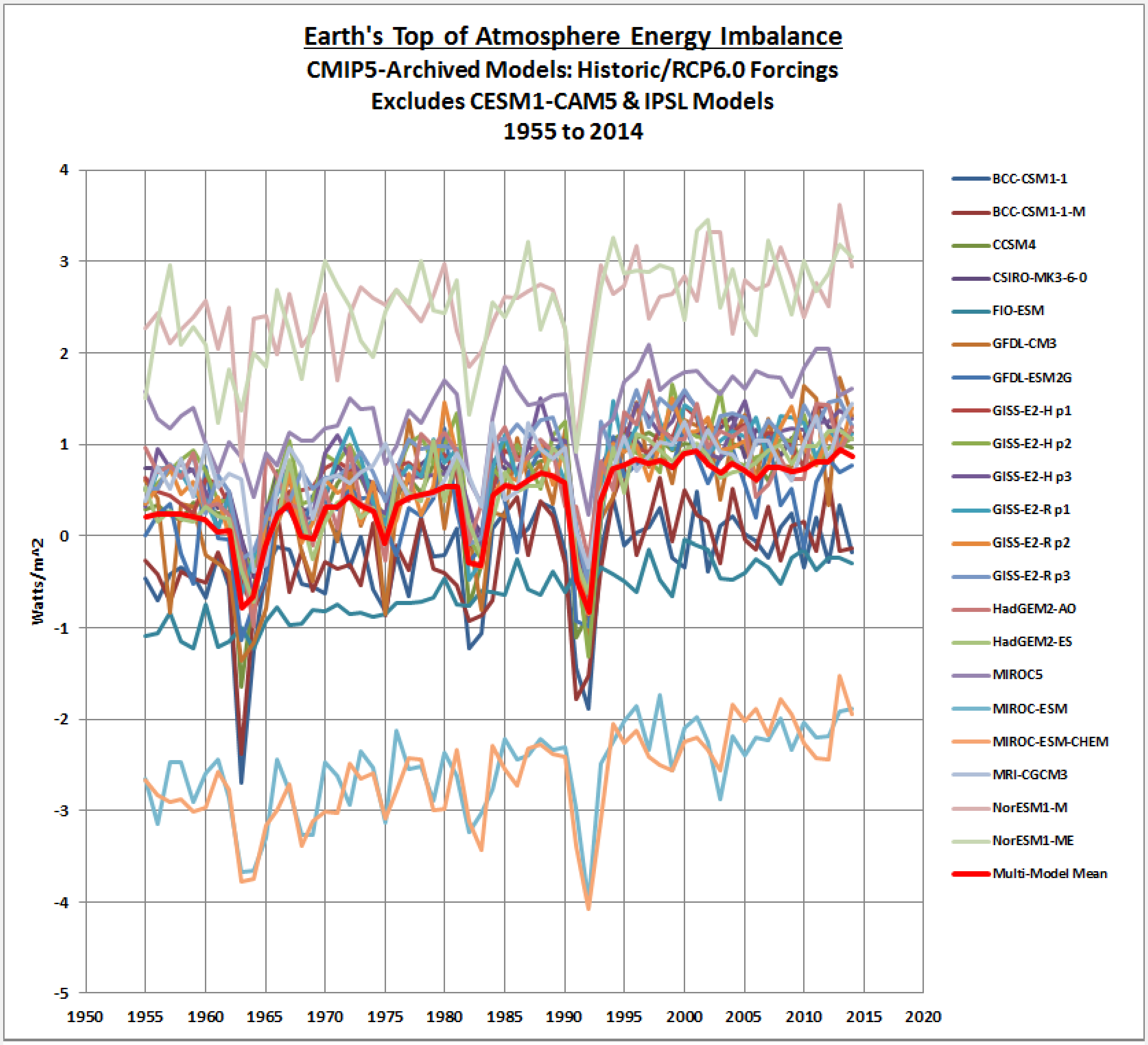


Figure 1.24-1

In *Chapter 1.10 – Introduction to Radiative Imbalance,* I presented the modeled energy imbalance at the top of the atmosphere (TOA). As you'll recall, there was a very wide spread in the individual model simulations of the top-of-the-atmosphere energy imbalance. (See Figure 1.10-3.) I've shortened the timeframe to 1955-2014 in Figure 1.24-1, which is the period for which ocean heat content data are available from the NODC.

Ponder that graph for a moment. The average top-of-the-atmosphere energy imbalance (red curve) in recent years is in the expected range…the range we've been told by the climate science community. Example: According to Trenberth et al. (2014) Earth's Energy Imbalance:

> *All estimates (OHC and TOA) show that over the past decade the energy imbalance ranges between about 0.5 and 1 Wm^{-2}.*

Trenberth et al. (2014) must not have been referring to the individual climate models, because they show a much larger range. In fact, some of the models show relatively high positive TOA energy imbalances, in the neighborhood of +2.5 watts/m^2, while others show negative energy imbalances, roughly -2.5 watts/m^2.

The simulated oceans in the models with the high positive top-of-the-atmosphere energy imbalances have to be accumulating heat at relatively fast rates. On the other hand, the simulated oceans in the models with the negative top-of-the-atmosphere energy imbalances have to be losing heat very quickly. Yes, losing heat.

In this chapter, we're going to calculate and illustrate the ocean heat accumulation from 1955 to 2014 based on the climate-model-simulated top-of-the-atmosphere energy imbalances for all of the models included in the earlier energy imbalance chapter (Chapter 1.10). We'll start with the full oceans compared to data for the top 2000 meters, and we'll then compare models and data for the top 700 meters.

INTRODUCTION

Because the oceans to depth have a tremendous capacity to store heat, they are supposed to be storing about 93% of the excess heat created by the emissions of man-made greenhouse gases. See Figure 1.24-2.

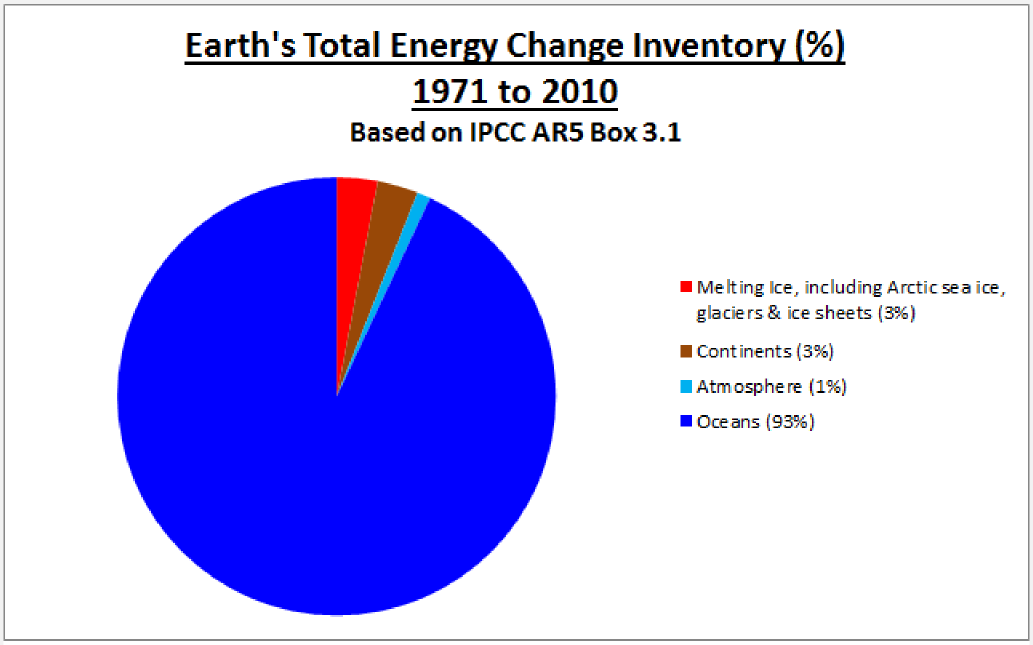


Figure 1.24-2

The pie chart in Figure 1.24-2 is based on the Earth's total energy change inventory from Box 3.1 of Chapter 3 – Observations: Oceans of the IPCC's 5th Assessment Report. There they write:

> *Ocean warming dominates the total energy change inventory, accounting for roughly 93% on average from 1971 to 2010 (high confidence). The upper ocean (0-700 m) accounts for about 64% of the total energy change inventory. Melting ice (including Arctic sea ice, ice sheets and glaciers) accounts for 3% of the total, and warming of the continents 3%. Warming of the atmosphere makes up the remaining 1%.*

We'll use the 64% value later in the chapter when we address the depths of 0-700 meters.

WE CAN USE THE MODELED ENERGY IMBALANCE AT THE TOP OF THE ATMOSPHERE TO DETERMINE HOW MUCH HEAT THE OCEANS SHOULD BE ACCUMULATING, ACCORDING TO THE MODELS

The ocean heat content outputs of the climate models stored in the Climate Model Intercomparison Project Phase 5 (CMIP5) archive are not available in easy-to-use form at the KNMI Climate Explorer. In fact, I know of no place where ocean heat content outputs are easy to access for any of the CMIP5-based models.

Fortunately, the components of the modeled Energy Imbalance at the Top of the Atmosphere (TOA) are available. So we can determine the energy imbalance, and, in turn, how much heat the oceans should be storing, according to the models. It's commonly done, as you'll see.

As you'll recall from *Chapter 1.10 – Introduction to Radiative Imbalance*, the energy imbalance at the top of the atmosphere is made up of 3 components (nomenclature and acronym used at the KNMI Climate Explorer are shown in parentheses):

1. the amount of sunlight reaching the top of the atmosphere (TOA Incident Shortwave Radiation, *rsdt*),
2. the sunlight being reflected back to space primarily by clouds and volcanic aerosols (TOA Outgoing Shortwave Radiation, *rsut*), and
3. the infrared radiation being emitted by Earth relative to the top of the atmosphere (TOA Outgoing Longwave Radiation, *rlut*).

The top of the atmosphere energy imbalance is calculated by subtracting the Outgoing Shortwave and Longwave Radiation from Incident Shortwave Radiation.

Figure 1.24-3 presents the average top-of-the-atmosphere energy imbalance of the climate models stored in the CMIP5 archive, specifically the multi-model mean of the models using historic and RCP6.0 forcings. We're discussing the multi-model mean now for simplicity sake…for those new to the topic. The 1955 to 2014 timeframe relates to the NODC's ocean heat content data for the depths 0-2000 meters (about 6600 feet or about 1.25 miles).

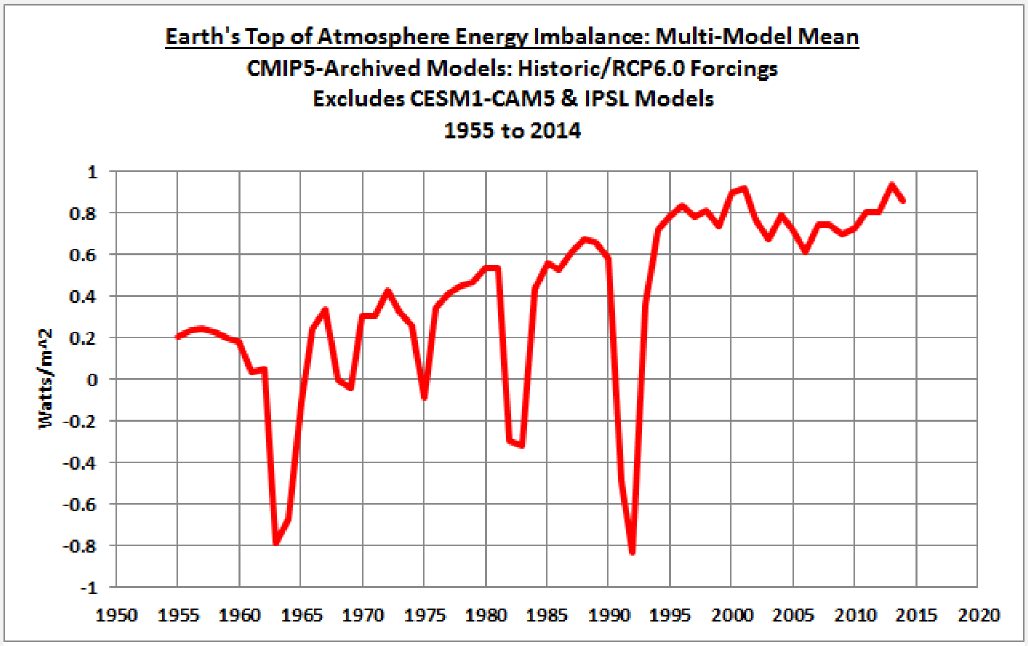


Figure 1.24-3

The large dips and rebounds in those model simulations are caused by the aerosols emitted into the stratosphere by explosive volcanic eruptions.

Each year that the top-of-the-atmosphere energy imbalance is positive, the oceans gain heat, and each year the top-of-the-atmosphere energy imbalance is negative, the oceans lose heat. The energy imbalance is positive most of the time, so the modeled oceans should be warming to depth, according to the model mean.

Note: You'll notice in the title block of Figure 1.24-3 that I excluded three models: CESM-CAM5 and two IPSL models. There were shifts at 2006 in the TOA Outgoing Longwave Radiation outputs of all three runs of the CESM-CAM5 model (one with a monstrous shift), which skewed the multi-model mean of that metric for that scenario. (I notified KNMI of that problem, and NCAR has since corrected them. I've continued to exclude them so that the models in this chapter are the same in the top-of-the-atmosphere energy imbalance chapter.) I also excluded the two IPSL models because their top-of-the-atmosphere Incident Shortwave Radiation contains a volcanic aerosol component, while all other models do not. (The other models address volcanic aerosols with the Outgoing Shortwave Radiation.)

That leaves 21 models, including BCC-CSM1-1, BCC-CSM1-1-M, CCSM4 (6 runs), CSIRO-MK3-6-0 (10 runs), FIO-ESM (3 runs), GFDL-CM3, GFDL-ESM2G, GISS-E2-H p1, GISS-E2-H p2, GISS-E2-H p3, GISS-E2-R p1, GISS-E2-R p2, GISS-E2-R p3, HadGEM2-AO, HadGEM2-ES (3 runs), MIROC5 (3 runs), MIROC-ESM, MIROC-ESM-CHEM, MRI-CGCM3, NorESM1-M, and NorESM1-ME.

For those models with multiple runs, the ensemble members are averaged before being included in the multi-model mean.

[End note.]

CONVERTING FROM WATTS/M^2 TO JOULES*10^22/YEAR

We'll need to convert the units of the modeled top-of-the-atmosphere energy imbalance (watts/m^2) to those used for ocean heat content to the depths of 2000 meters (Joules * 10^22).

Apparently, the climate science community also uses TOA energy imbalance to determine ocean heat uptake. Gavin Schmidt presented two conversion factors (the one he originally used in his model-data comparisons at RealClimate and the corrected one) in his post OHC Model/Obs Comparison Errata.

> *My error was in assuming that the model output (which were in units W yr/m2) were scaled for the ocean area only, when in fact they were scaled for the entire global surface area (see fig. 2 in Hansen et al, 2005). Therefore, in converting to*

> *units of 10^{22} Joules for the absolute ocean heat content change, I had used a factor of 1.1 (0.7 x 5.1 x 365 x 3600 x 24 x 10^{-8}), instead of the correct value of 1.61 (5.1 x 365 x 3600 x 24 x 10^{-8}).*

The paper Dr. Schmidt referenced is Hansen et al. (2005) Earth's energy imbalance: Confirmation and implications. That papers notes:

> ***Ocean heat storage**. Confirmation of the planetary energy imbalance can be obtained by measuring the heat content of the ocean, which must be the principal reservoir for excess energy (3, 15). Levitus et al. (15) compiled ocean temperature data that yielded increased ocean heat content of about 10 W year/m2, averaged over the Earth's surface, during 1955 to 1998 [1 W year/m2 over the full Earth ~ 1.61 x 10^{22} J…].*

Referring back to Dr. Schmidt's post at RealClimate, unfortunately, Gavin didn't present the units for those factors. So let's add the units:

1.61*10^22 Joules/year per watt/m^2 = (Earth's surface area 5.1*10^14 m^2)*(365 days/year)*(3600 seconds/hour)*(24 hours/day)

We'll make one more adjustment to the conversion factor. We'll assume the oceans are accumulating 93% of the top-of-the-atmosphere energy imbalance, which lowers the conversion factor to 1.50*10^22 Joules/year per watt/m^2.

MODELED ANNUAL OCEAN HEAT UPTAKE AND ACCUMULATION BASED ON THE MODEL MEAN (FULL OCEAN)

Based on that conversion factor, the annual modeled ocean heat uptake (absolute) for the full oceans that was derived from the simulated top-of-the-atmosphere energy imbalance are shown in Figure 1.24-4…again using the model mean to simplify these early discussions. Basically, Figure 1.24-4 illustrates the average of the modeled top-of-the-atmosphere energy imbalance but in terms used for ocean heat content. Every year the value is positive, the oceans gain heat, and each year the value is negative, the oceans lose heat. The difference between an annual value and zero indicates how much heat the oceans gain or lose in a given year. In other words, the graph shows the annual ocean warming and cooling rates for the global oceans.

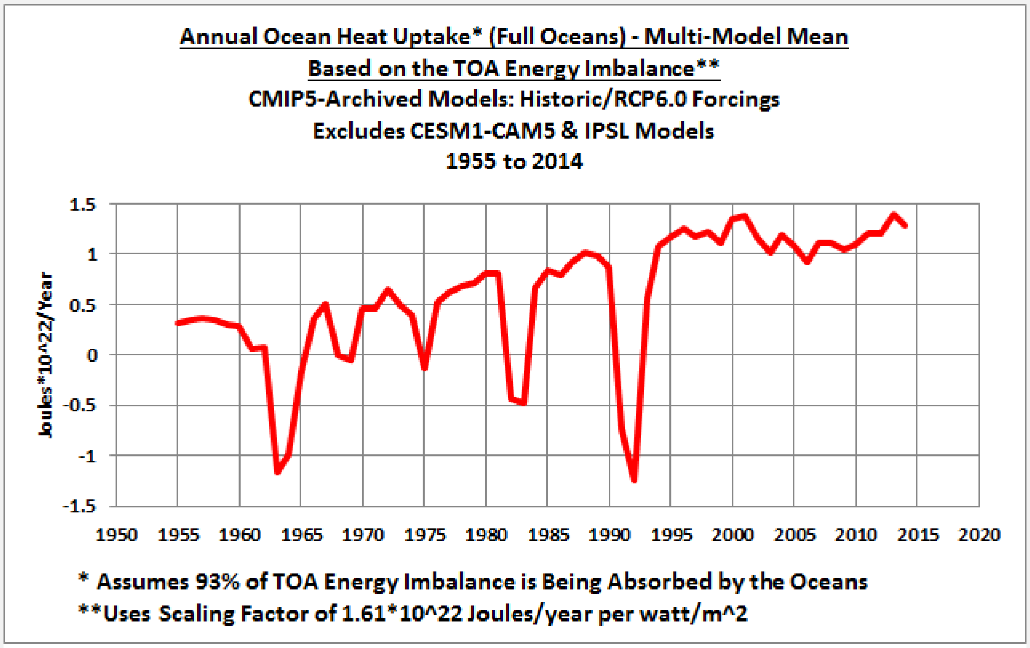


Figure 1.24-4

But that still doesn't allow us to directly compare the models to the data. The (much-adjusted) global ocean heat content data from the NODC for the depths of 0-2000 meters are presenting how much heat the oceans are accumulating in the top 2000 meters. To determine the modeled ocean heat accumulation, we simply take a running total (cumulative sum) of the annual heat uptake…like the balance in a bank account. See Figure 1.24-5.

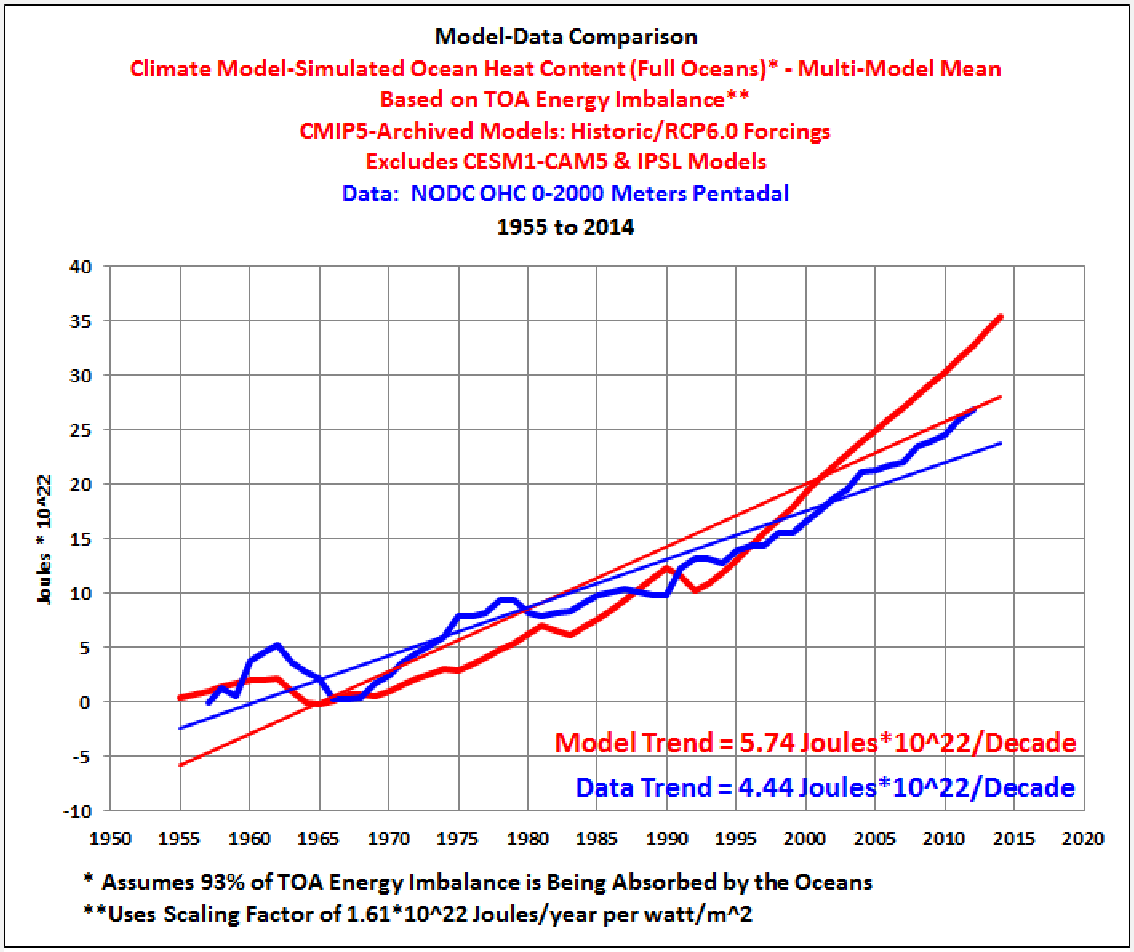


Figure 1.24-5

I've included the NODC ocean heat content reconstruction for the top 2000 meters (zeroed at 1957) in pentadal form as a reference for the (much-adjusted) observations. (Data here.) The data have been shifted so that the 1957 value is zero. That was done solely to ease the visual comparisons. Keep in mind, before the early 2000s when the ARGO floats were deployed, the NODC ocean heat content data for the top 2000 meters are based on very few temperature and salinity measurements. Phrased differently, before the ARGO era, the NODC ocean heat content data to depths of 2000 meters are basically make-believe data. We'll discuss and illustrate this in more detail in the future Part 2 of this book.

For the sake of discussion, we'll assume there is no heat gain below 2000 meters. It's commonly done. That is, we'll assume all of the excess heat is being absorbed only in the top 2000 meters. That's consistent with the findings of Liang et al. (2015) Vertical Redistribution of Oceanic Heat Content. (See the preprint copy here.) In fact, Liang et al. found (1) the oceans below 2000 meters had cooled from 1992 to 2012 and (2) part of the heat above 2000 meters was from the redistribution of heat upwards from the depths below 2000 meters. By assuming all of the observed heat gain is in the top

2000 meters, we can then compare the data to the model outputs, the latter of which are for the full ocean, from surface to floor.

With those things considered, it might be misleadingly said that the models, as represented by the model mean, do a reasonable job of simulating the observed warming rate of the oceans. Why misleadingly? As we've already shown (Figure 1.24-1), there is no agreement among the models on the energy imbalance at the top of the atmosphere, and that means there is no agreement among the models on how much heat the oceans are accumulating…if they are in fact accumulating and not losing heat in their modeled oceans.

MODELED ANNUAL OCEAN HEAT UPTAKE AND ACCUMULATION FOR ALL MODELS (FULL OCEAN)

Using the conversion factor presented earlier (1.06*10^22 Joules/year per watt/m^2), the annual heat uptake and losses (absolute) in modeled ocean heat content, for the full oceans, based on the simulated top-of-the-atmosphere energy imbalance from 1955 to 2014, are shown in Figure 1.24-6…this time for the model mean (in red) and the individual models stored in the CMIP5 archive using the historic and RCP6.0 forcings. Again, in other words, Figure 1.24-6 illustrates the modeled energy imbalance of the individual models but in the terms used for ocean heat content, which is why it looks so similar to Figure 1.24-1.

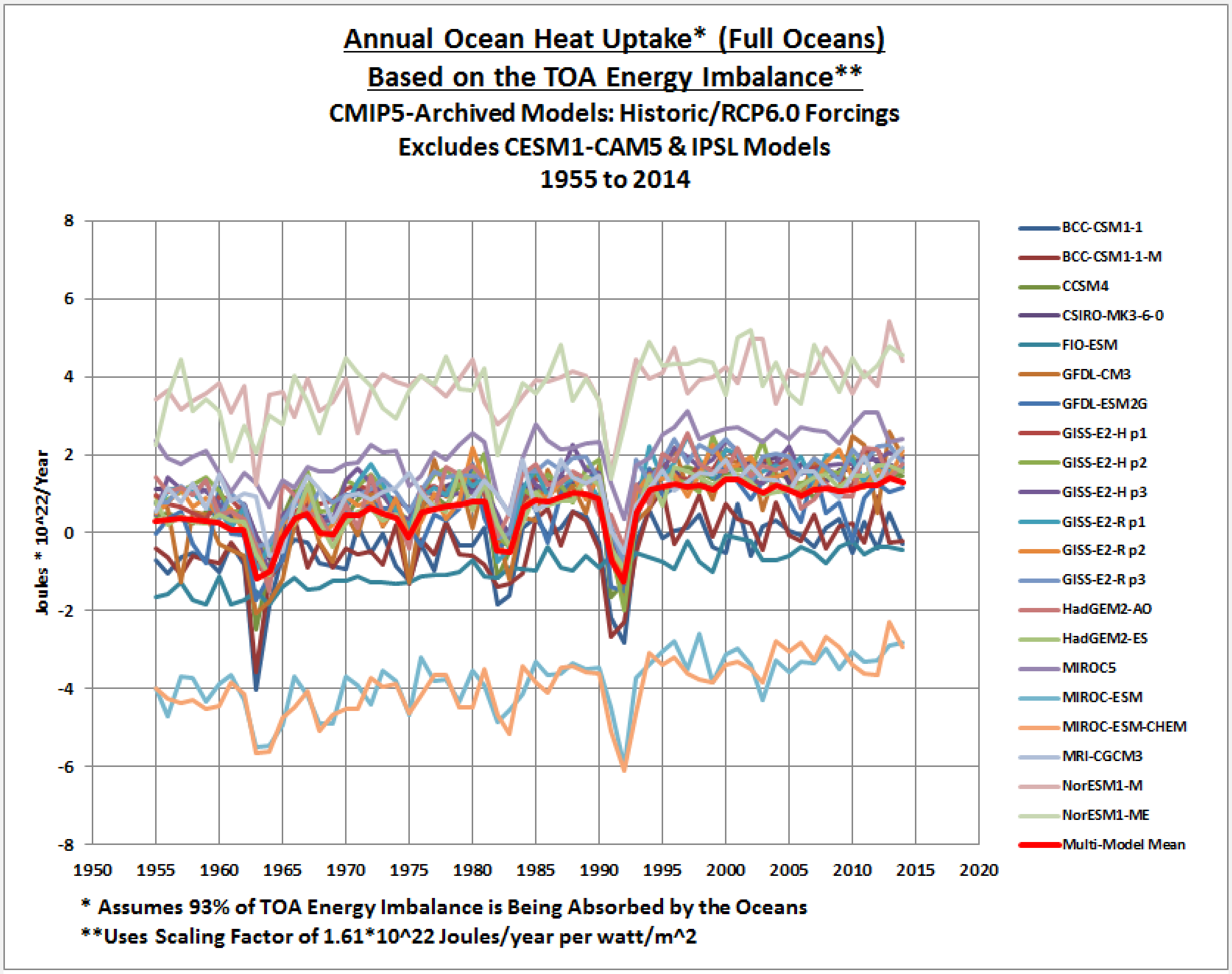


Figure 1.24-6

The simulated oceans in the models with higher absolute positive values are gaining heat faster than those whose energy imbalances are closer to zero. And the oceans in the models with the negative imbalances from 1955 to 2014 are not accumulating heat; they're losing it.

The models with the high positive imbalances and with the negative imbalances are obvious outliers. They create remarkable ocean heat content curves that should probably be considered implausible. See Figure 1.24-7. Yet they are among the models used by the IPCC for their 5th Assessment Report. Then again, if we were to eliminate models because they didn't simulate some metric properly, there would be no climate models left in the CMIP archives.

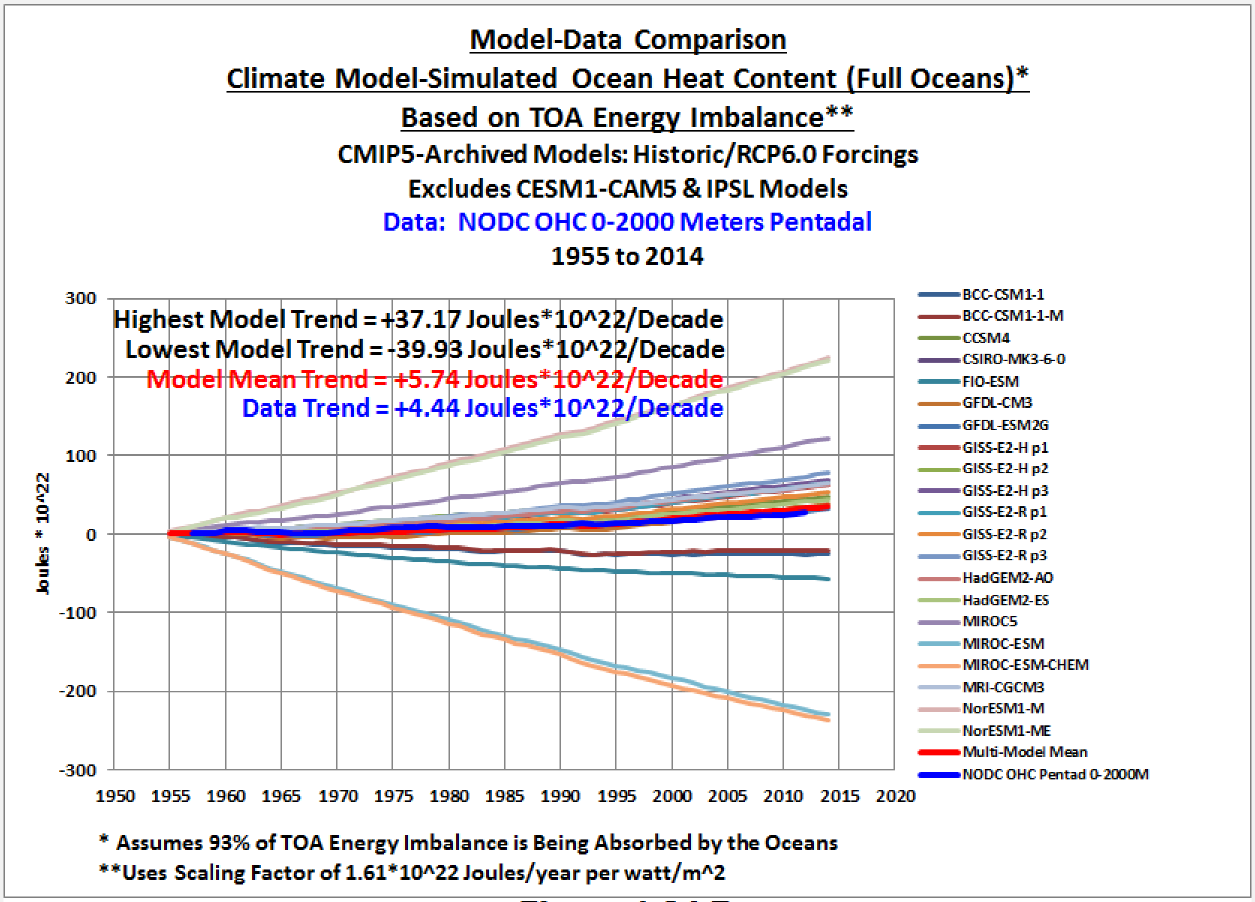


Figure 1.24-7

Obviously, based on the climate models used by the IPCC for their 5th Assessment Report, there is no agreement on how much heat the oceans should be accumulating, or even if the oceans are accumulating heat, based on their energy imbalances. And the differences in the simulated ocean heat accumulation are so great that using the model mean to represent the models is very misleading.

THE IPCC'S PRESENTATION IS TOTALLY DIFFERENT

Figure 1.24-8 is Figure 9.17 from Chapter 9 – Evaluation of Climate Models from the IPCC's 5th Assessment Report. The middle graph, Cell b, corresponds to my Figure 1.24-7 above. Surprisingly, there are few similarities between the two presentations. The primary difference between the IPCC's and my comparison graphs of ocean heat accumulation is that the IPCC has adjusted the climate model outputs in its graph. I've underlined in red the sentence where the IPCC states that in the caption. It reads:

> *Simulation drift has been removed from all CMIP5 runs with a contemporaneous portion of a quadratic fit to each corresponding pre-industrial control run (Gleckler et al., 2012).*

Figure 9.17 from Chapter 9 of IPCC's 5th Assessment Report

Chapter 9 | Evaluation of Climate Models

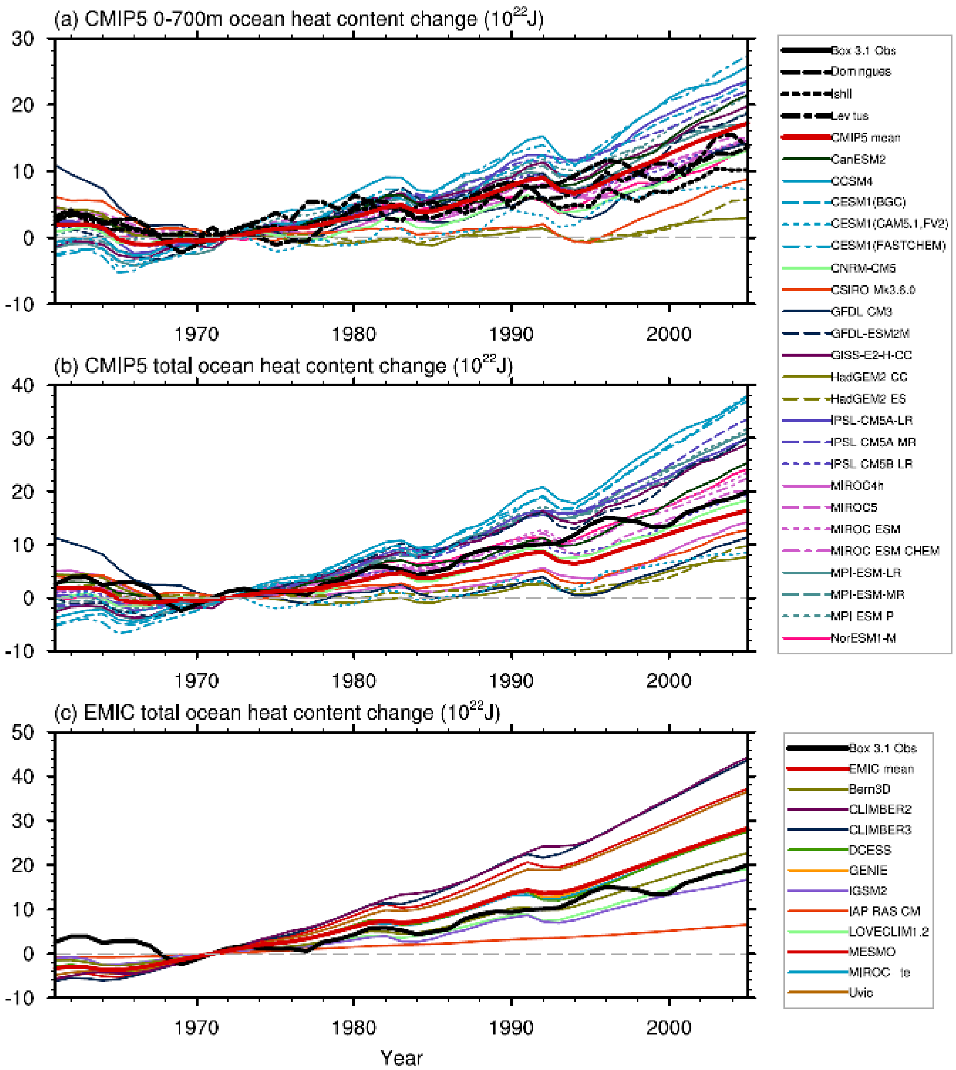


Figure 9.17 | Time series of simulated and observed global ocean heat content anomalies (with respect to 1971). CMIP5 historical simulations and observations for both the upper 700 meters of the ocean (a) as well as for the total ocean heat content (b). Total ocean heat content results are also shown for EMICs and observations (c). EMIC estimates are based on time-integrated surface heat flux into the ocean. The 0 to 700 m and total heat content observational estimates (thick lines) are respectively described in Figure 3.2 and Box 3.1, Figure 1. Simulation drift has been removed from all CMIP5 runs with a contemporaneous portion of a quadratic fit to each corresponding pre-industrial control run (Gleckler et al., 2012). Units are 10^{22} Joules.

Figure 1.24-8

Note: Climate model "drift" is, basically, a phenomenon where the climate model outputs can change with time even if the inputs were to be kept constant. The problem is discussed in Sen Gupta et al. (2013) Climate Drift in CMIP5 Models (paywalled). The abstract reads (my boldface):

> ***Climate models often exhibit spurious long-term changes independent of either internal variability or changes to external forcing****. Such changes, referred to as model "drift," may distort the estimate of forced change in transient climate simulations. The importance of drift is examined in comparison to historical trends over recent decades in the Coupled Model Intercomparison Project (CMIP). Comparison based on a selection of metrics suggests a significant overall reduction in the magnitude of drift from phase 3 of CMIP (CMIP3) to phase 5 of CMIP (CMIP5). The direction of both ocean and atmospheric drift is systematically biased in some models introducing statistically significant drift in globally averaged metrics. Nevertheless, for most models globally averaged drift remains weak compared to the associated forced trends and is often smaller than the difference between trends derived from different ensemble members or the error introduced by the aliasing of natural variability.* ***An exception to this is metrics that include the deep ocean (e.g., steric sea level) where drift can dominate in forced simulations. In such circumstances drift must be corrected for using information from concurrent control experiments.*** *Many CMIP5 models now include ocean biogeochemistry. Like physical models, biogeochemical models generally undergo long spinup integrations to minimize drift. Nevertheless, based on a limited subset of models, it is found that drift is an important consideration and must be accounted for. For properties or regions where drift is important, the drift correction method must be carefully considered. The use of a drift estimate based on the full control time series is recommended to minimize the contamination of the drift estimate by internal variability.*

In other words, because of model flaws, climate model outputs are adjusted by climate scientists when simulating the deep oceans. Let's rephrase that: Because of inherent flaws in climate models, when examining model performance, climate scientists will adjust the outputs of climate models before comparing them to data. How bizarre is that?

LET'S RETURN TO OUR TOA ENERGY IMBALANCE-BASED OCEAN HEAT CONTENT AND ELIMINATE THE OUTLIERS (FULL OCEAN)

Three of the 21 models in Figure 3.24-7 are showing way too much heat accumulation, and 5 of the models show the oceans losing heat because of their negative TOP-OF-THE-ATMOSPHERE energy imbalances. They are so far from the much-adjusted observations I've excluded them in Figure 1.24-9.

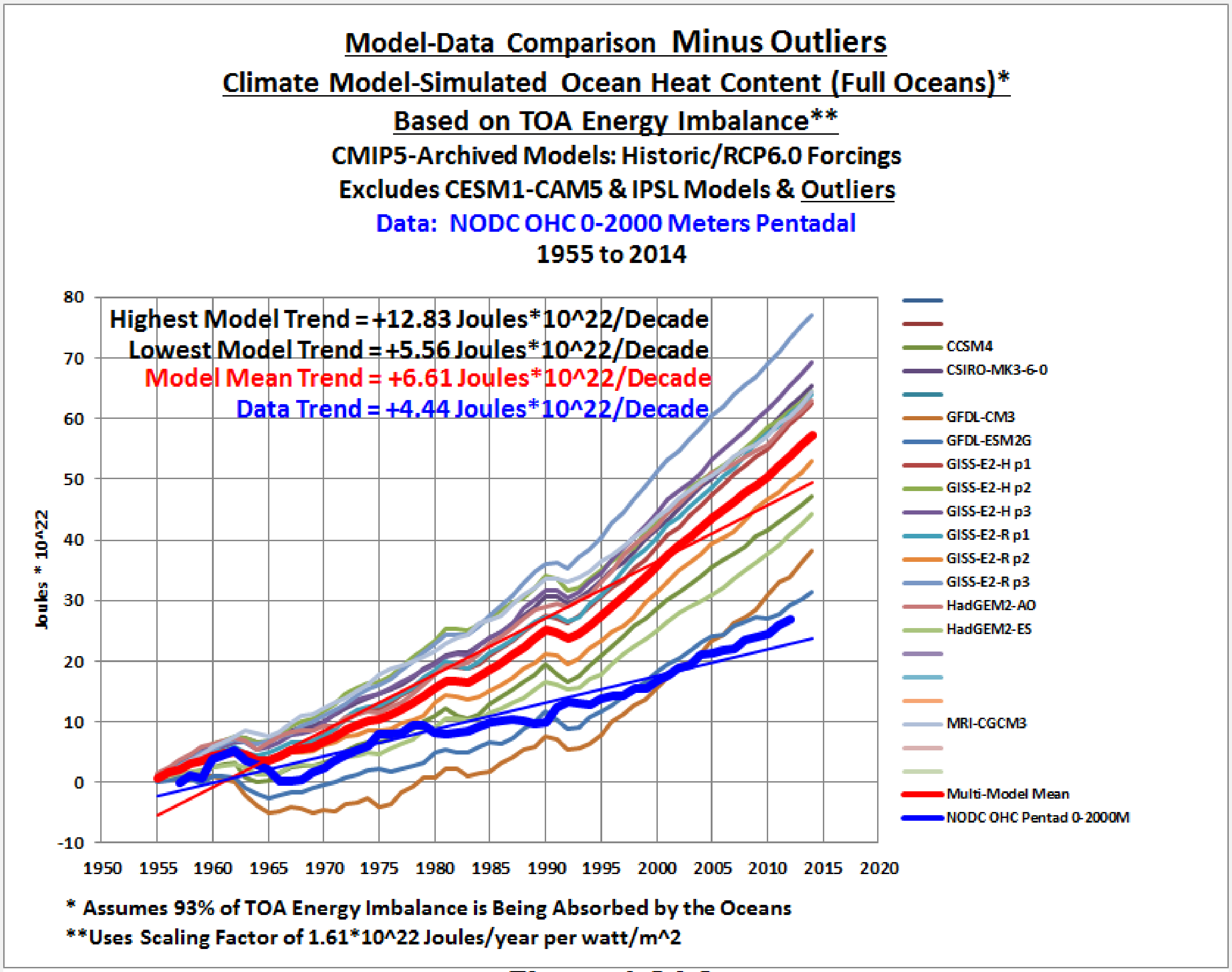


Figure 1.24-9

But eliminating the outliers creates other problems for the models. With the obvious outliers removed, not one of the remaining 13 models has an ocean heat content trend that's lower than the observed trend. In other words, all of the models are showing too much warming. And that means, for most the remaining models, the climate sensitivities to CO_2 are too high.

With the outliers removed, according to the model mean, the models are showing a heat accumulation that's about 50% to higher than observed.

WHAT ABOUT THE GISS MODEL E2 SIMULATIONS FROM THE CMIP5 ARCHIVE (FULL OCEAN)?

For a number of years, Gavin Schmidt (the director of the Goddard Institute of Space Studies, GISS) presented model-data comparisons at RealClimate that included simulated and observed ocean heat content for different depths. Gavin compared models and data for the depths of 0-700 meters in the posts that appeared in December 2009, May 2010, January 2011 and February 2012. It was only in the last post that Dr. Schmidt presented the comparison for the modeled full ocean and data for 0-2000 meters. We'll illustrate the model-data comparison for the top 700 meters in a moment, but let's first stick with the data for the top 2000 meters and the modeled ocean heat accumulation for the full oceans.

You'll note that the ocean heat content graphs in those RealClimate posts have been corrected per Gavin's May 2012 post OHC Model/Obs Comparison Errata. The ocean heat content comparisons in them used the GISS models from the earlier CMIP3 archive. Gavin Schmidt closed his errata post with:

> *Analyses of the CMIP5 models will provide some insight here since the historical simulations have been extended to 2012 (including the last solar minimum), and have updated aerosol emissions. Watch this space.*

I suspect some of you, like me, have been patiently waiting for those CMIP5-archived GISS Model E2-based model-data comparisons for ocean heat content. Yet, for more than three years, none have been posted at RealClimate.

For those interested, Figure 1.24-10 compares the data with the top-of-the-atmosphere energy imbalance-based ocean heat content for the three GISS Model E2-R simulations…along with the mean of those 3 runs. The "R" suffix letter stands for the Russell Ocean model that's coupled to the GISS Model E.

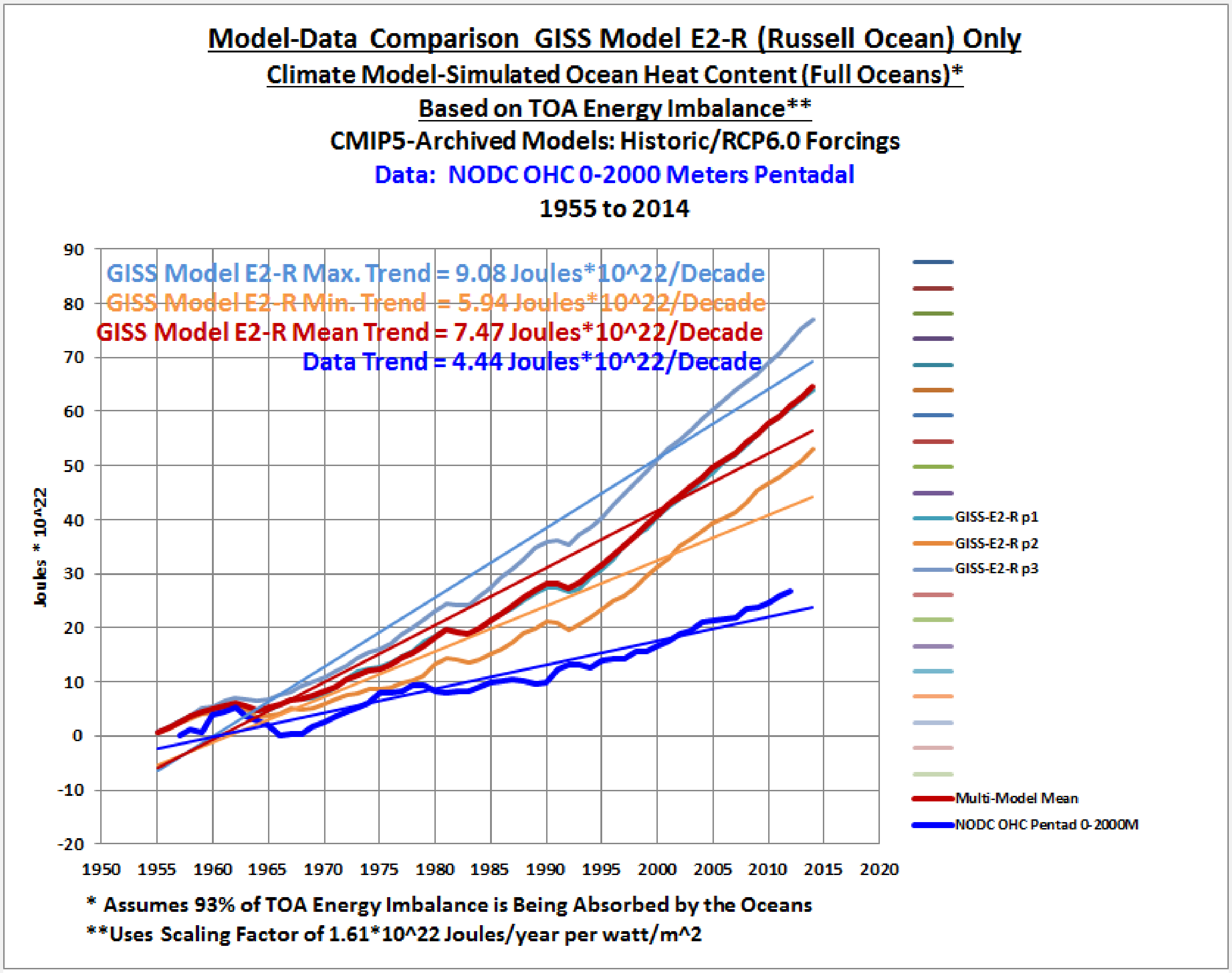


Figure 1.24-10

This batch of GISS climate models is showing that they are too sensitive to CO_2 by a wide amount. The modeled heat accumulation shown by the model mean of this GISS model is almost 70% higher than shown by the data.

Looking at the legends in Figures 1.24-6, -7 and -9, you'll note that GISS also has another group of model experiments with an "H" suffix. The "H" stands for HYCOM ocean. Figure 1.24-11 includes the model-data comparison of the GISS models with the HYCOM oceans.

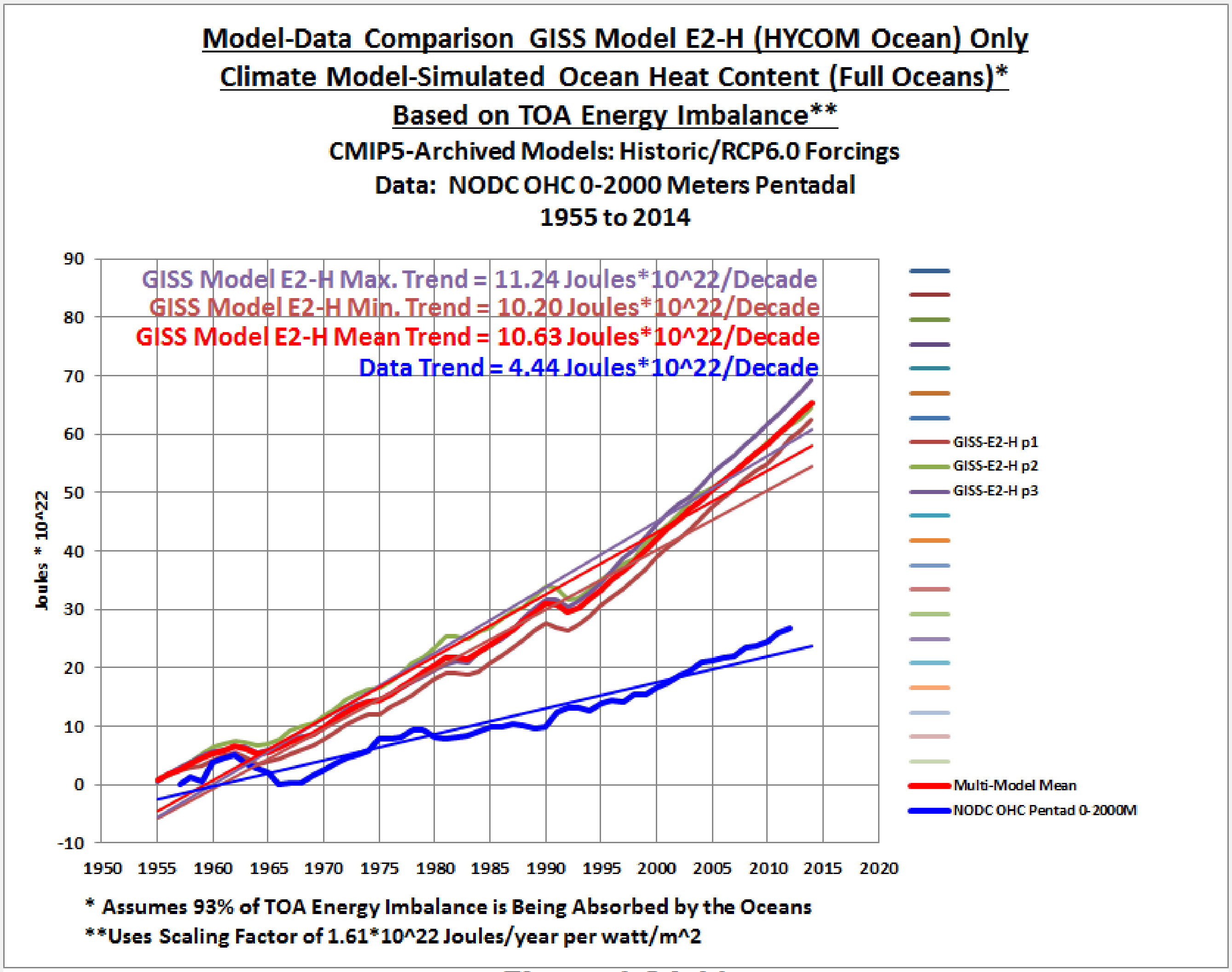


Figure 1.24-11

Once again, the GISS models show they are way too sensitive to CO_2. This time the model mean of this GISS model shows a heat accumulation that's more than twice the observations.

I'll let you speculate about why there have been no model-data comparisons of ocean heat content at RealClimate for 3 years.

MODEL-DATA FOR 0-700 METERS

We'll be using the annual NODC ocean heat content data (0-700m) here in the following comparisons. For the comparisons I've simply shifted the data so that the 1955 value is zero.

There is better sampling at the depths of 0-700 meters than at 700-2000 meters before the ARGO era, so the NODC ocean heat content data for the depths of 0-700 meters is a better dataset. While sampling at these upper depths may be better globally, they are still very poor in the southern hemisphere. With that in mind…

For these comparisons we'll rely on the IPCC's statement that "*The upper ocean (0-700 m) accounts for about 64% of the total energy change inventory…"* from the earlier quote. That is, we're taking the scaling factor (1.61*10^22 Joules/year per watt/m^2) and multiplying it by 0.64 to determine the annual ocean heat content uptake for the top 700 meters of the oceans from the top-of-the-atmosphere energy imbalance. The following are the pertinent graphs without commentary, because the comments would basically be the same as those for the full oceans.

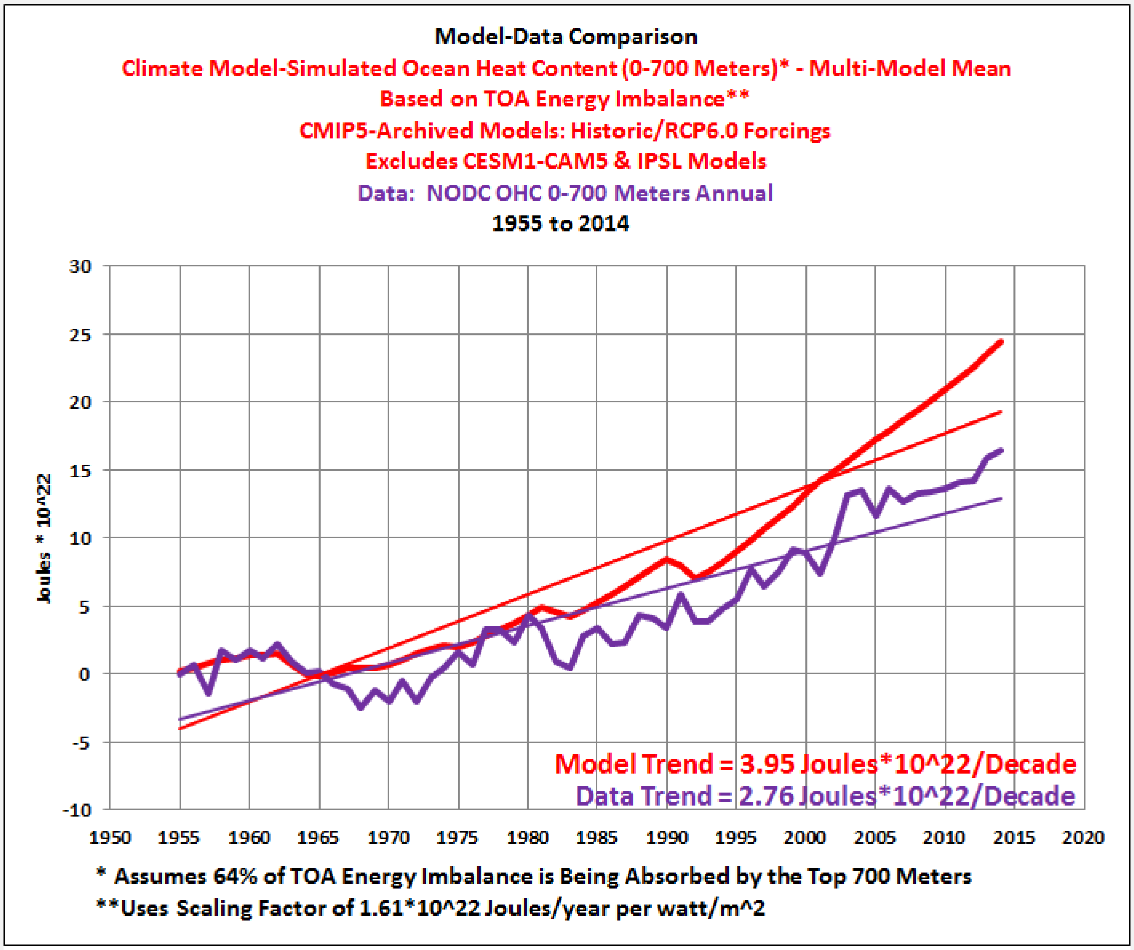


Figure 1.24-12

# # #

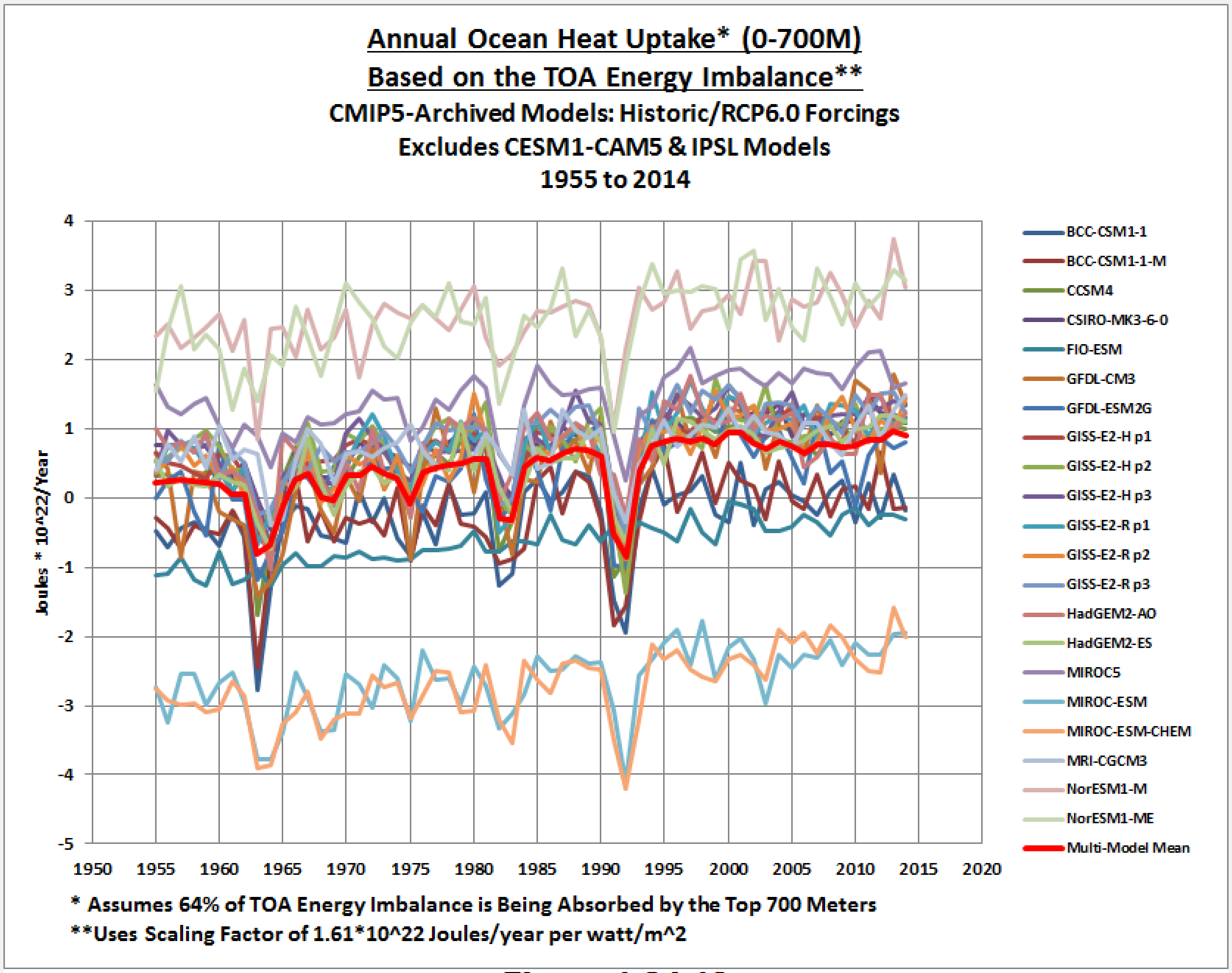


Figure 1.24-13

# # #

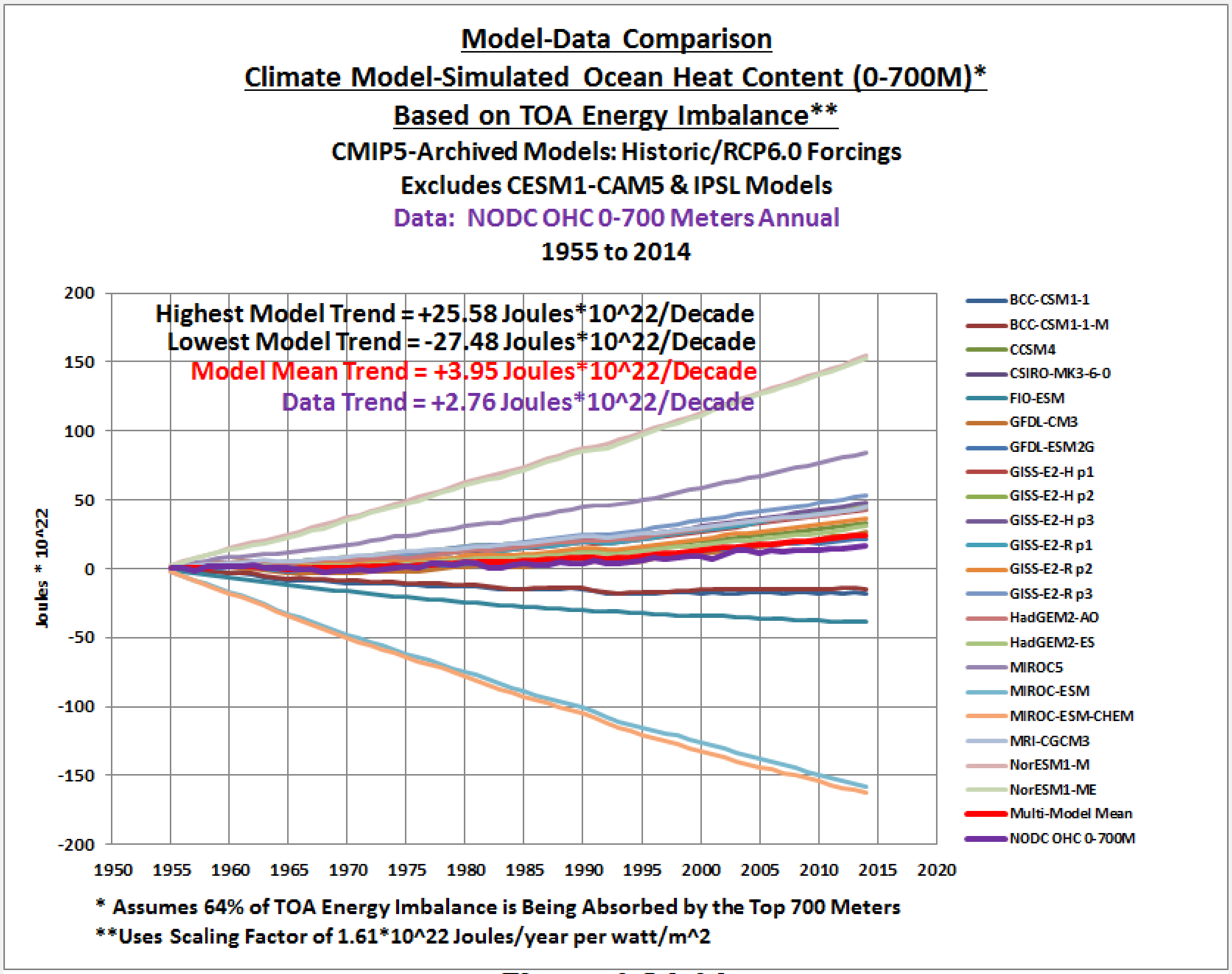


Figure 1.24-14

# # #

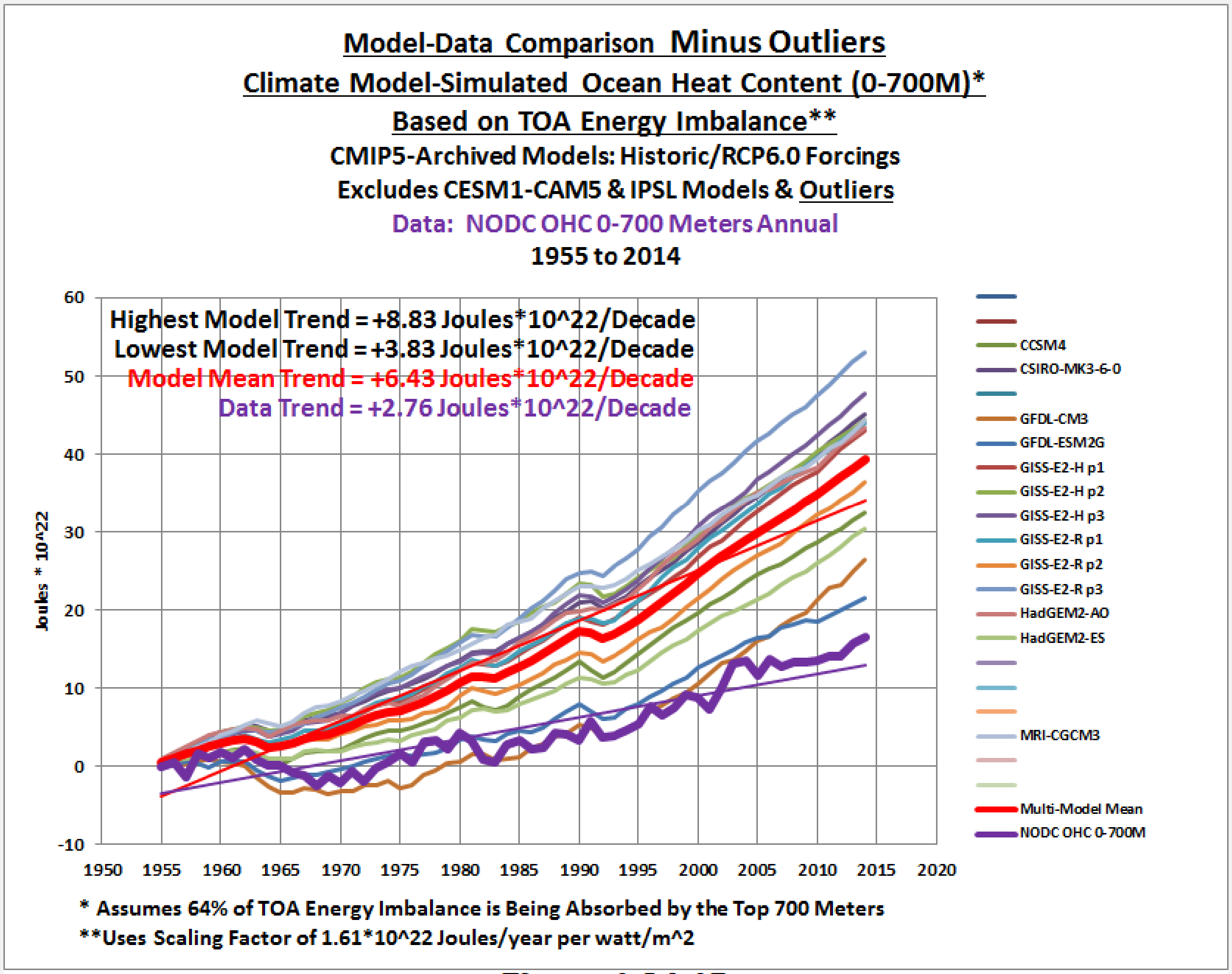


Figure 1.24-15

# # #

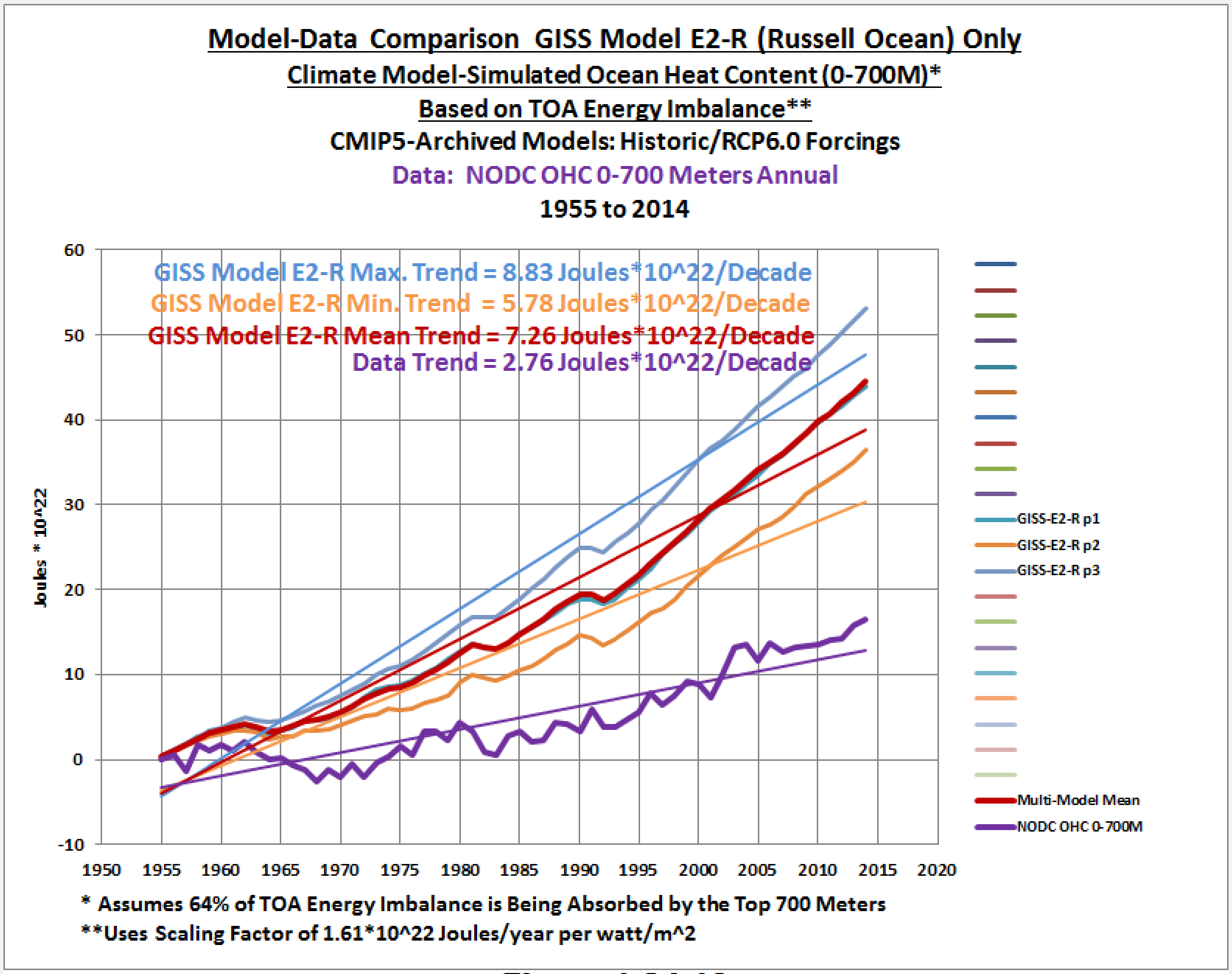


Figure 1.24-16

# # #

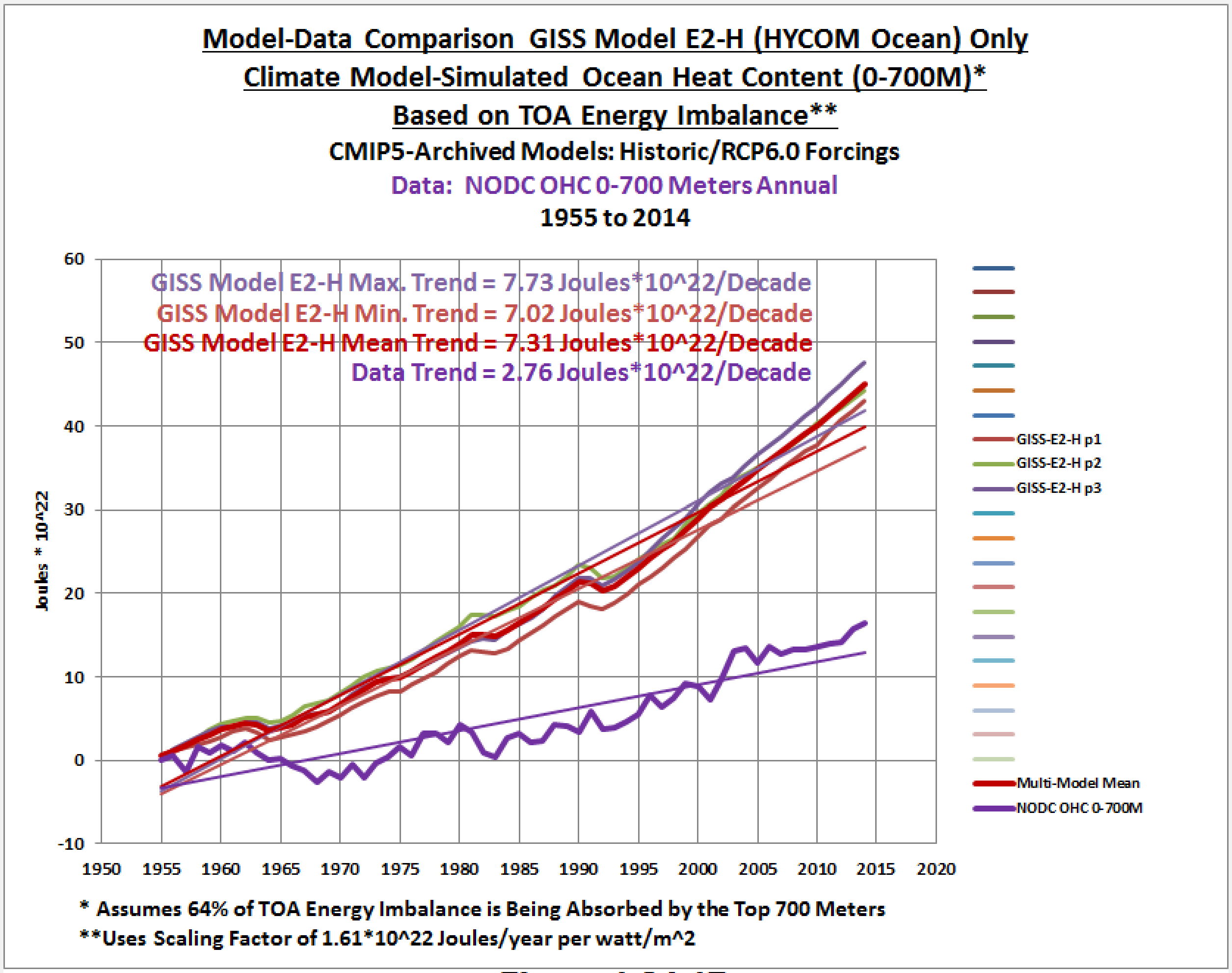


Figure 1.24-17

CLOSING

The energy imbalance at the top of the atmosphere and ocean heat accumulation are crucial elements in the hypothesis of human-induced global warming. Because there is no agreement among the climate models about the energy imbalance at the top of the atmosphere (Figure 1.24-1), there can be no agreement among the climate models about the heat accumulating in the oceans (Figures 1.24-7 and 1.24-14).

With the unlikely outliers removed, or referring to the GISS Model E2-R and GISS Model E2-H simulations, the differences between the observed and modeled ocean heat accumulation indicate the models are much too sensitive to the hypothetical impacts of CO_2.

With the outliers removed, according to the model mean, the models are showing a heat accumulation that's about 50% higher than observed for the depths of 0-2000 meters and more than twice the observed heat accumulation for the depths of 0-700 meters.

And depending on the GISS climate model and depth, the modeled heat accumulation can be two to three times higher than what has been observed.

Many of the modeled oceans in the models used by the IPCC for their 5th Assessment Report are not storing heat close to the (much-adjusted) observed rates, so those models are not simulating global warming as it exists on Earth. But there's really nothing new about that either. We can simply add ocean heat accumulation and top-of-the-atmosphere energy imbalance to the list of things that climate models do not simulate properly: like surface temperatures, like precipitation, like polar sea ice, like polar amplification, like El Niño and La Niña processes, like the Atlantic Multidecadal Oscillation, like the Pacific Decadal Oscillation, and so on.

Once again, climate models have shown they are good for one thing and one thing only: to display how poorly they simulate Earth's climate.

Important Note: As discussed, because of inherent flaws in climate models like model drift, when examining model performance, climate scientists will adjust the outputs of climate models before comparing them to data.

THANKS

This chapter is based on my blog post Climate Models Fail: Global Ocean Heat Content (Based on TOA Energy Imbalance). As you'll note in that post, I purposely used the wrong scaling factor for converting the top-of-the-atmosphere energy imbalance to ocean heat uptake. I did that because I found it odd that the trends of the observations aligned almost perfectly with the trends of the model mean for the full oceans and for the top 700 meters. While it's likely only a coincidence, it appeared as though the models were tuned to the wrong scaling factor.

Many thanks to Willis Eschenbach and Roger Pielke, Sr. for their comments on the initial (but much different) drafts of that blog post and to researcher Nic Lewis for his comments on the thread of the cross post at WattsUpWithThat.

1.25 – Many, But Not All, Climate Metrics Are Presented in Anomaly and in Absolute Forms

For the first part of this chapter about *anomalies*, I'm going to borrow a discussion I've used in my earlier books. We'll then expand on that discussion and also look at data and models in absolute form.

ANOMALIES AND THEIR USE

With rare exceptions, surface temperature data and model outputs in this book are presented as anomalies, not as absolutes. To see why anomalies are used, let's take a look at monthly global surface temperatures in absolute form. Figure 1.25-1 shows monthly global surface temperatures from January, 1950 to October, 2011. As you can see, there are wide seasonal swings in global surface temperatures every year.

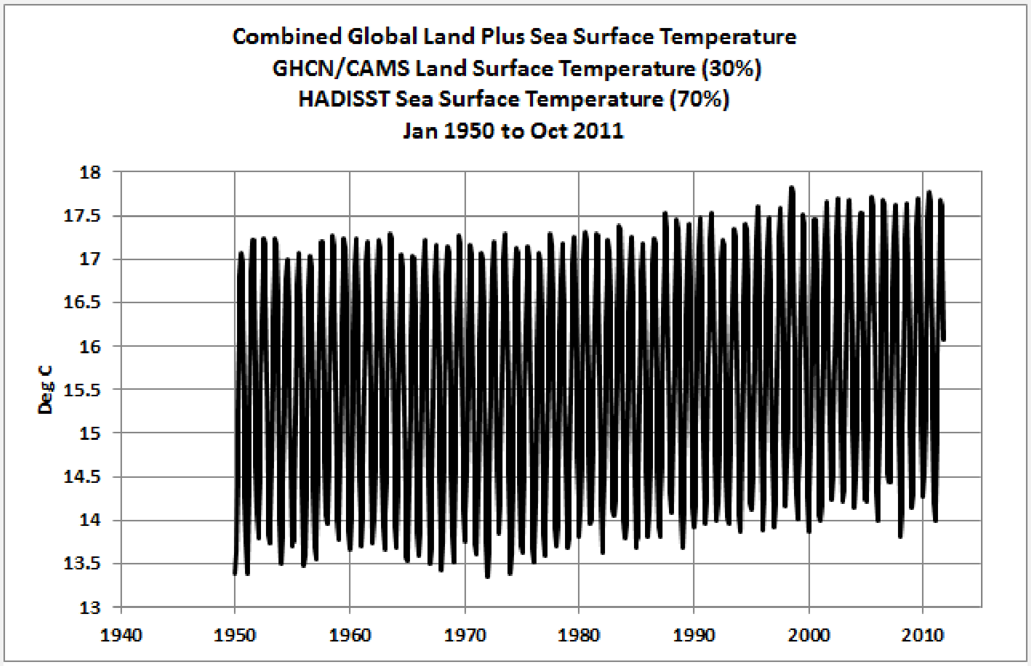


Figure 1.25-1

In fact, it's easy to see that the annual cycles in monthly global surface temperatures are much greater than the long-term warming that's supposedly bad.

Note: The three producers of global surface temperature datasets are the NASA GISS (Goddard Institute for Space Studies), the NCDC (NOAA National Climatic Data Center), and the United Kingdom's National Weather Service known as the UKMO (UK Met Office). Those global surface temperature products are only available in anomaly form. (We'll discuss the reasons given for this in a few moments.) As a result, to create Figure 1.25-1, I needed to combine land and sea surface temperature datasets that are available in absolute form. I used GHCN+CAMS land surface air temperature reanalysis from NOAA and the HADISST Sea Surface Temperature data from the UK Met Office Hadley Centre. Land covers about 30% of the Earth's surface, so the data in Figure 1.25-1 is a weighted average of land surface temperature data (30%) and sea surface temperature data (70%). [End note.]

When looking at absolute surface temperatures (Figure 1.25-1), it's really difficult to determine if and why there are changes in global surface temperatures from one year to the next; the annual cycles are so large that they limit one's ability to see when there are changes. Also note that the variations in the annual minimums do not always coincide with the variations in the maximums. You can see that the temperatures have warmed, but you can't determine the changes from month to month or year to year.

Take the example of comparing the ocean surface temperatures of the Northern and Southern Hemispheres using the satellite-era sea surface temperatures in Figure 1.25-2. The seasonal signals in the data from the two hemispheres oppose each other. When the Northern Hemisphere is warming as winter changes to summer, the Southern Hemisphere is cooling because it's going from summer to winter at the same time. Those two datasets are 180 degrees out of phase.

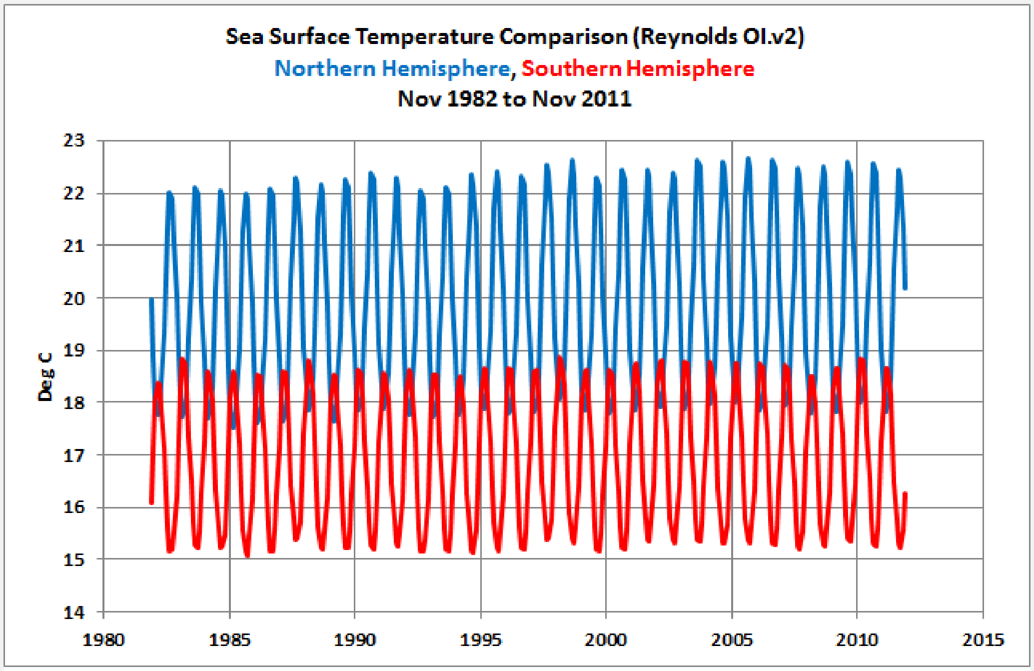


Figure 1.25-2

After converting that data to anomalies (Figure 1.25-3), the two datasets are easier to compare.

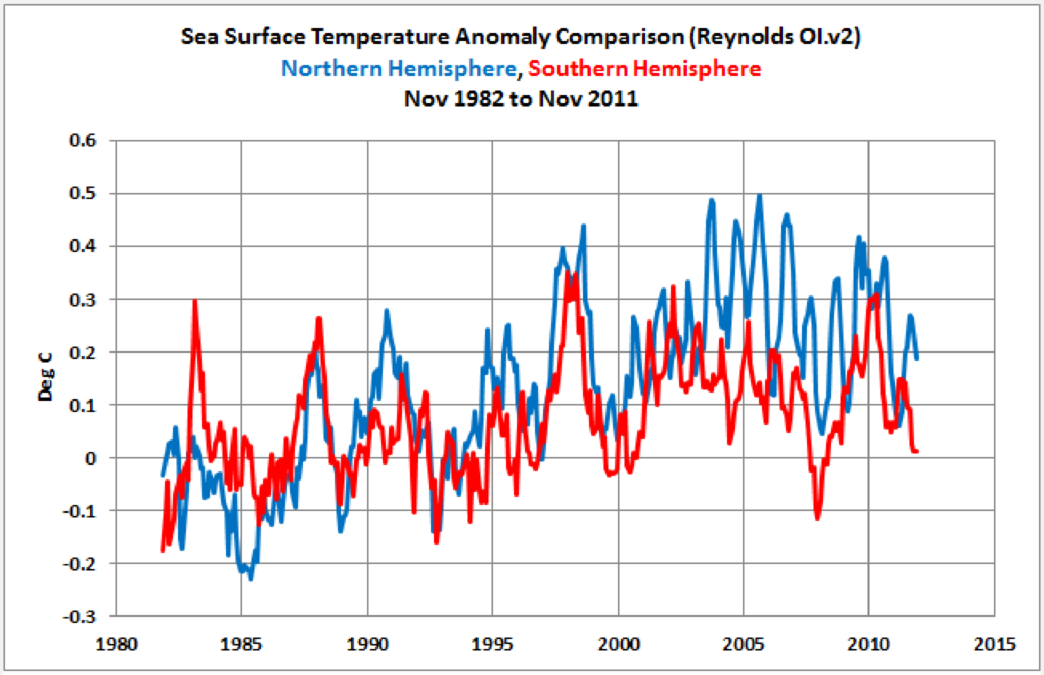


Figure 1.25-3

# # #

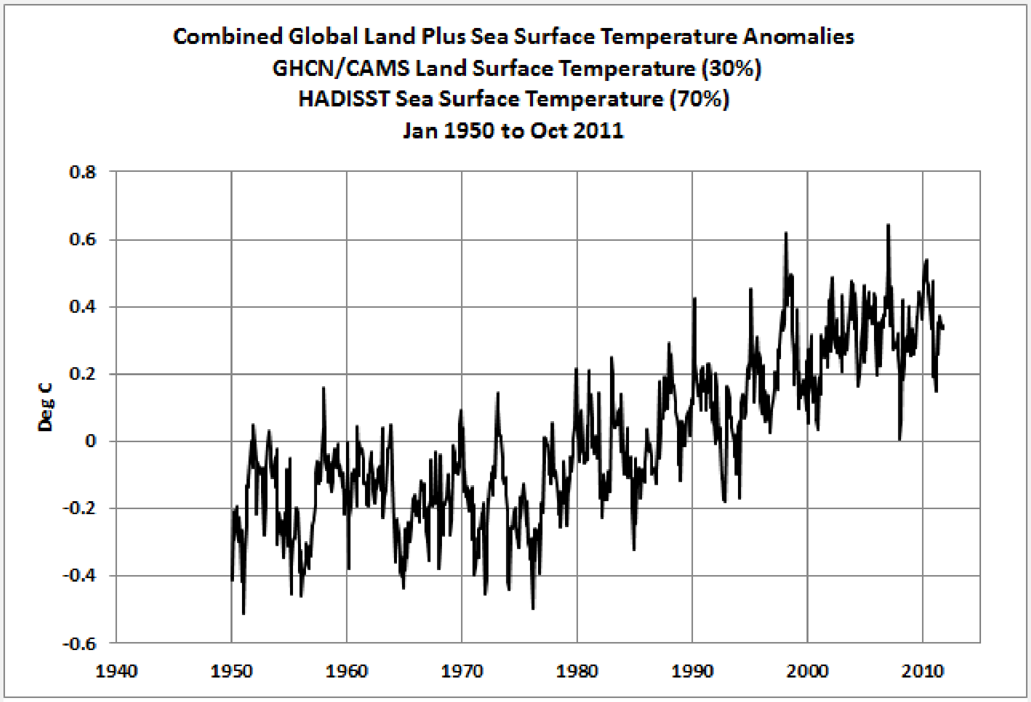


Figure 1.25-4

Returning to the global land-plus-sea surface temperature data, once you convert the same data to anomalies, as was done in Figure 1.25-4, you can see that there are significant changes in global surface temperatures that aren't related to the annual seasonal cycle. The upward spikes every couple of years are caused by El Niño events. Most of the downward spikes are caused by La Niña events. (We'll discuss El Niño and La Niña events in detail in Chapter 3.7. They are parts of a very interesting process that nature created.) Some of the drops in temperature are caused by the aerosols ejected from explosive volcanic eruptions. Those aerosols reduce the amount of sunlight that reaches the surface of the Earth, cooling it temporarily. Temperatures rebound over the next few years as volcanic aerosols dissipate.

There is, of course, another reason why data are presented in anomaly form. Suppose you wanted to compare the surface temperatures of the tropical Pacific with those of the Southern Ocean, which surrounds Antarctica, to determine if there are any similarities in the annual wiggles. The differences in temperatures between the tropics and the polar oceans are so great that the comparison would be difficult at best. By using anomalies in such a case, the temperatures are shifted to a common reference point, making the comparison much easier.

HOW TO CALCULATE ANOMALIES

Climate research tools like the KNMI Climate Explorer will calculate anomalies for you. The following is for those persons interested in how anomalies are determined.

To convert the absolute surface temperatures shown in Figure 1.25-1 into the anomalies presented in Figure 1.25-4, you must first choose a reference period. The reference period is often referred to as the "base years." I use the base years of 1950 to 2010 for this example.

The process: First, determine average temperatures for each month during the reference period. That is, average all the surface temperatures for all the Januaries from 1950 to 2010. Do the same thing for all the Februaries, Marches, and so on, through the Decembers during the reference period; each month is averaged separately. Those are the reference temperatures. Second, determine the anomalies, which are calculated as the differences between the reference temperatures and the observed temperatures for a given month. That is, to determine the January, 1950 temperature anomaly, subtract the average January surface temperature from the January, 1950 value. Because the January, 1950 surface temperature was below the average temperature of the reference period, the anomaly has a negative value. If it had been higher than the reference-period average, the anomaly would have been positive. The process continues as February, 1950 is compared to the reference-period average temperature for Februaries. Then March, 1950 is compared to the reference-period average temperature for Marches, and so on, through the last month of the data, which in this example was October 2011. It's easy to create a spreadsheet to do this, but, thankfully, data sources like the KNMI Climate Explorer website do all of those calculations for you, so you can save a few steps.

SUMMARY OF INITIAL DISCUSSION ABOUT ANOMALIES

Anomalies are used instead of absolutes because anomalies remove most of the large seasonal cycles inherent in the temperature, precipitation, and sea ice area data and model outputs. Using anomalies makes it easier to see the monthly and annual variations and makes comparing data and model outputs on a single graph much easier.

WHY THE THREE PRIMARY SUPPLIERS OF GLOBAL SURFACE TEMPERATURE PRODUCTS USE ANOMALIES AS OPPOSED TO ABSOLUTES

The following is the part of the text from my January 2014 blog post Why Aren't Global Surface Temperature Data Produced in Absolute Form?

GISS EXPLANATION

GISS on their webpage here states:

> *Anomalies and Absolute Temperatures*
>
> *Our analysis concerns only temperature anomalies, not absolute temperature. Temperature anomalies are computed relative to the base period 1951-1980. The reason to work with anomalies, rather than absolute temperature is that absolute temperature varies markedly in short distances, while monthly or annual temperature anomalies are representative of a much larger region. Indeed, we have shown (Hansen and Lebedeff, 1987) that temperature anomalies are strongly correlated out to distances of the order of 1000 km. For a more detailed discussion, see The Elusive Absolute Surface Air Temperature.*

UKMO-HADLEY CENTRE EXPLANATION

The UKMO-Hadley Centre answers that question…and why they use 1961-1990 as their base period for anomalies on their webpage here.

> Why are the temperatures expressed as anomalies from 1961-90?
>
> *Stations on land are at different elevations, and different countries measure average monthly temperatures using different methods and formulae. To avoid biases that could result from these problems, monthly average temperatures are reduced to anomalies from the period with best coverage (1961-90). For stations to be used, an estimate of the base period average must be calculated. Because many stations do not have complete records for the 1961-90 period several*

> *methods have been developed to estimate 1961-90 averages from neighbouring records or using other sources of data (see more discussion on this and other points in Jones* et al. *2012). Over the oceans, where observations are generally made from mobile platforms, it is impossible to assemble long series of actual temperatures for fixed points. However it is possible to interpolate historical data to create spatially complete reference climatologies (averages for 1961-90) so that individual observations can be compared with a local normal for the given day of the year (more discussion in Kennedy* et al. *2011).*
>
> *It is possible to develop an absolute temperature series for any area selected, using the absolute file, and then add this to a regional average in anomalies calculated from the gridded data. If for example a regional average is required, users should calculate a time series in anomalies, then average the absolute file for the same region then add the average derived to each of the values in the time series. Do NOT add the absolute values to every grid box in each monthly field and then calculate large-scale averages.*

NCDC EXPLANATION

Also see the NCDC (Now NCEI.) FAQ webpage here. They state:

> *Absolute estimates of global average surface temperature are difficult to compile for several reasons. Some regions have few temperature measurement stations (e.g., the Sahara Desert) and interpolation must be made over large, data-sparse regions. In mountainous areas, most observations come from the inhabited valleys, so the effect of elevation on a region's average temperature must be considered as well. For example, a summer month over an area may be cooler than average, both at a mountain top and in a nearby valley, but the absolute temperatures will be quite different at the two locations. The use of anomalies in this case will show that temperatures for both locations were below average.*
>
> *Using reference values computed on smaller [more local] scales over the same time period establishes a baseline from which anomalies are calculated. This effectively normalizes the data so they can be compared and combined to more accurately represent temperature patterns with respect to what is normal for different places within a region.*
>
> *For these reasons, large-area summaries incorporate anomalies, not the temperature itself. Anomalies more accurately describe climate variability over larger areas than absolute temperatures do, and they give a frame of reference that allows more meaningful comparisons between locations and more accurate calculations of temperature trends.*

SURFACE TEMPERATURE DATASETS AND A REANALYSIS THAT ARE AVAILABLE IN ABSOLUTE FORM

Most sea surface temperature datasets are available in absolute form. These include:

- the Reynolds OI.v2 SST data from NOAA
- the NOAA reconstruction ERSST
- the Hadley Centre reconstruction HADISST
- and the source data for the reconstructions ICOADS

The Hadley Centre's HADSST3, which is used in the HADCRUT4 product, is only produced in absolute form, however.

All of those datasets are available to download through the KNMI Climate Explorer Monthly Observations webpage. Scroll down to SST and select a dataset. For further information about the use of the KNMI Climate Explorer see the posts Very Basic Introduction To The KNMI Climate Explorer and Step-By-Step Instructions for Creating a Climate-Related Model-Data Comparison Graph.

GHCN-CAMS is a reanalysis of land surface air temperatures, and it is presented in absolute form. It must be kept in mind, though, that a reanalysis is not "raw" data; it is the output of a climate model that uses data as inputs. GHCN-CAMS is also available through the KNMI Climate Explorer and identified as "1948-now: CPC GHCN/CAMS t2m analysis (land)". I first presented it in the post Absolute Land Surface Temperature Reanalysis back in 2010.

[End of discussion from that blog post.]

IS GHCN-CAMS SUITABLE FOR MODEL-DATA COMPARISONS?

The GHCN-CAMS reanalysis is supported by the 2008 Fan and van den Dool paper A global monthly land surface air temperature analysis for 1948-present. The abstract reads (my boldface):

> A station observation-based global land monthly mean surface air temperature dataset at 0.5 _ 0.5 latitude-longitude resolution for the period from 1948 to the present was developed recently at the Climate Prediction Center, National Centers for Environmental Prediction. This data set is different from some existing surface air temperature data sets in: (1) using a combination of two large individual data sets of station observations collected from the Global Historical Climatology Network version 2 and the Climate Anomaly Monitoring System (GHCN + CAMS), so it can be regularly updated in near real time with plenty of stations and (2) some unique interpolation methods, such as the anomaly interpolation approach with spatially-temporally varying temperature lapse rates

> derived from the observation-based Reanalysis for topographic adjustment. When compared with several existing observation-based land surface air temperature data sets, the preliminary results show that the quality of this new GHCN + CAMS land surface air temperature analysis is reasonably good and the new data set can capture most common temporal-spatial features in the observed climatology and anomaly fields over both regional and global domains. The study also reveals that there are clear biases between the observed surface air temperature and the existing Reanalysis data sets, and they vary in space and seasons. **Therefore the Reanalysis 2 m temperature data sets may not be suitable for model forcing and validation. The GHCN + CAMS data set will be mainly used as one of land surface meteorological forcing inputs to derive other land surface variables, such as soil moisture, evaporation, surface runoff, snow accumulation and snow melt, etc. As a byproduct, this monthly mean surface air temperature data set can also be applied to monitor surface air temperature variations over global land routinely or to verify the performance of model simulation and prediction.**

I was once criticized for using the GHCN-CAMS reanalysis in a model-data comparison in the 2013 post Model-Data Comparison: Australia Land Surface Air Temperatures & Anomalies – not so 'angry' after all. (Cross post at my blog is here.) For the criticism, see the post Candy from a Baby by statistician Grant Foster, who blogs by the name of Tamino. Grant Foster writes:

> *Tisdale goes for a surface temperature data set which is actually reanalysis data (i.e., a computer model fed with observations) which, as Nick Stokes again points out, is known to be biased. In the paper which introduced it you don't even need to read past the abstract to find that the authors themselves warn* "The study also reveals that there are clear biases between the observed surface air temperature and the existing Reanalysis data sets, and they vary in space and seasons. Therefore the Reanalysis 2 m temperature data sets may not be suitable for model forcing and validation."

While I did revise my post to indicate that GHCN-CAMS is a reanalysis, Grant Foster was up to his usual misinformation. If he had bothered to read Fan and van den Dool (2008), he would have discovered that the GHCN-CAMS reanalysis is not the "Reanalysis 2 m temperature data sets". In fact, had Grant Foster's followers read the rest of the abstract, they would have discovered Tamino's misrepresentation…they would have noted that Fan and van den Dool specifically state about the GHCN-CAMS reanalysis (my boldface):

> *As a byproduct, this monthly mean surface air temperature data set can also be applied to monitor surface air temperature variations over global land routinely or **to verify the performance of model simulation and prediction**.*

So to answer the question posed by the heading: Yes, the GHCN-CAMS surface temperature reanalysis can be used for model-data comparisons.

WHY THE THREE PRIMARY SUPPLIERS OF GLOBAL SURFACE TEMPERATURE PRODUCTS USE DIFFERENT BASE YEARS

In the quote above from the UKMO, they explained the period of 1961-1990 had the "best coverage" as the reason why they use that period for the base years for anomalies:

> *To avoid biases that could result from these problems, monthly average temperatures are reduced to anomalies from the period with best coverage (1961-90).*

GISS uses the period of 1951-1980 to remain consistent with their early publications and because there's better coverage after 1950. They state this in Hansen et al. (2010) Global Surface Temperature Change:

> *The GISS analysis uses 1951–1980 as the base period. The United States National Weather Service uses a 3 decade period to define "normal" or average temperature. When we began our global temperature analyses and comparisons with climate models, that climatology period was 1951–1980. There is considerable merit in keeping the base period fixed, including the fact that many graphs have been published with that choice for climatology. Besides, a different base period only alters the zero point for anomalies, without changing the magnitude of the temperature change over any given period. Note also that many of today's adults grew up during that period, so they can remember what climate was like then. Finally, the data for a base period must have good global coverage, which eliminates periods prior to the 1950s.*

That leaves NOAA. On their Background Information – FAQ webpage for Global Surface Temperature Anomalies, NOAA states:

> *9. Why do some of the products use different reference periods?*
>
> *The national maps show temperature anomalies relative to the 1981–2010 base period. This period is used in order to comply with a recommended World Meteorological Organization (WMO) Policy, which suggests using the latest decade for the 30-year average. For the global-scale averages (global land and ocean, land-only, ocean-only, and hemispheric time series), the reference period*

> *is adjusted to the 20th Century average for conceptual simplicity (the period is more familiar to more people, and establishes a longer-term average). The adjustment does not change the shape of the time series or affect the trends within it.*

Well, that wasn't very scientific. The 20th Century "is more familiar to more people" than the WMO-recommended 1981-2010 period? How odd! Sounds like misdirection there, doesn't it?

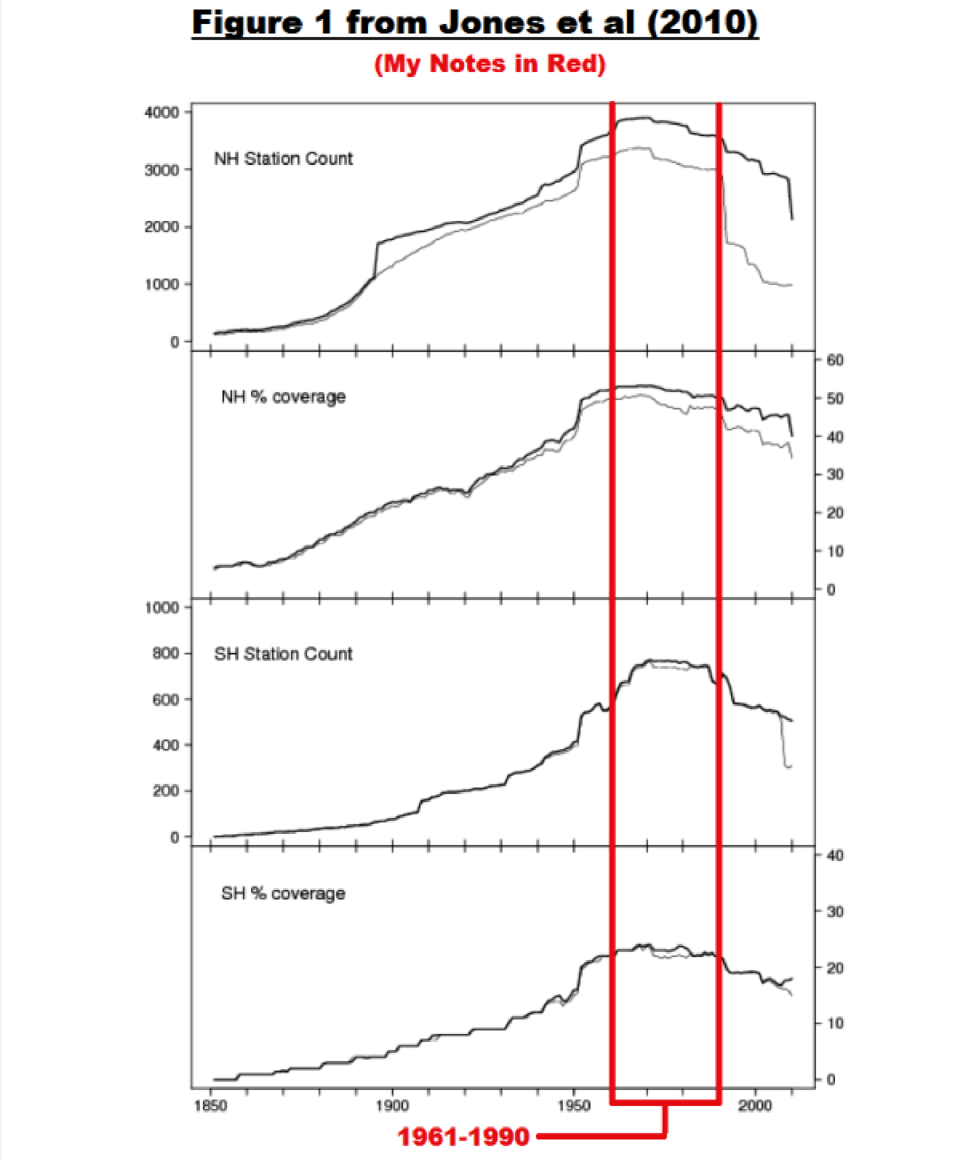


Figure 1: Comparison of station counts and percent area coverage (of the entire hemisphere including oceans) for CRUTEM4 (thick) and CRUTEM3 (thin) for the NH and SH.

Figure 1.25-5

We would have to assume, when the UKMO and GISS are talking about global "coverage", they're discussing land surface temperature measurements, not ocean surface temperatures. See Figure 1.25-5, which is Figure 1 from Jones et al. (2010) Hemispheric and large-scale land surface air temperature variations: An extensive revision and an update to 2010.

Sea surface temperature measurements, on the other hand, increased drastically in recent years with the concerted effort to distribute “drifting buoys” around the surfaces of the global oceans. (Drifters are not to be confused with ARGO floats.)

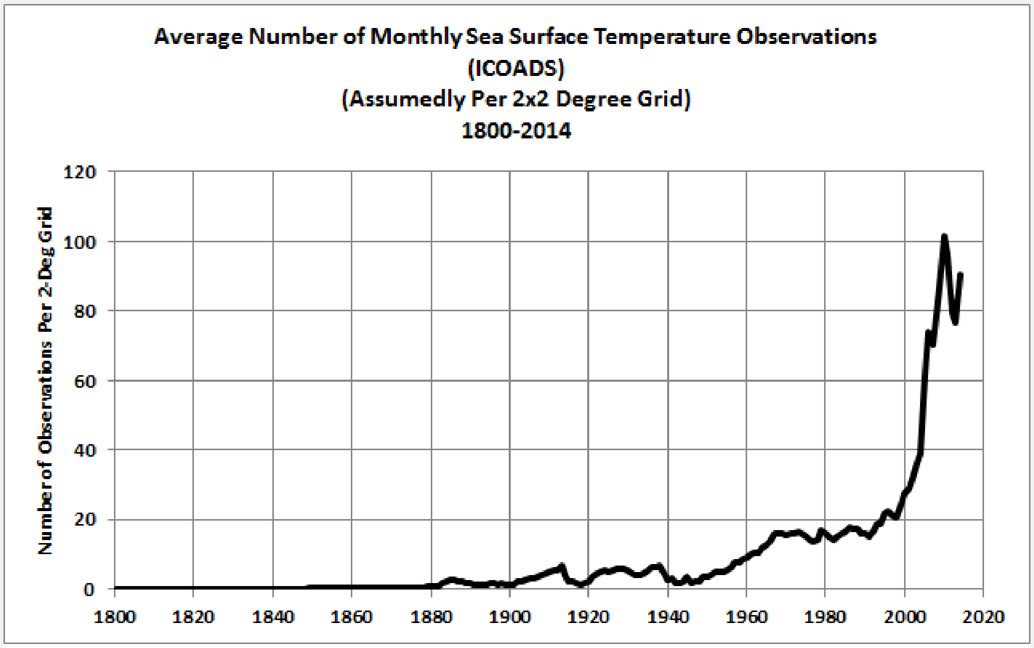


Figure 1.25-6

Figure 1.25-6 presents the number of observations (assumedly the average per 2.0 deg latitude by 2.0 degree longitude grid) for the ICOADS sea surface temperature data, which is the source of the much-adjusted sea surface temperature data used in global temperature products. The number of observations for the ICOADS source data are available at the KNMI Climate Explorer. The number of sea surface temperature measurements from buckets, ship inlet and buoys skyrocketed in the early 2000s.

Not too surprisingly, when global surface temperature product suppliers use spatial coverage of temperature measurements as excuses for their outdated reference periods for anomalies, they’re referring to land surfaces which only cover 30% of the globe.

OUTDATED REFERENCE PERIODS FOR GLOBAL TEMPERATURE ANOMALIES MAKE IT SEEM WARMER

Let’s compare the global surface temperature anomalies using the chosen base years from the three suppliers, and we’ll throw in the WMO-recommended base years of 1981-2010 and an oddball choice of 1901-1950 use by the IPCC in their 4th Assessment Report. Much of the following was included in *Chapter 2.2 - The Subtle Differences*

Due to the Base Years Used for Anomalies from my book Climate Models Fail, which is why the graph ends in 2012.

Reference periods (the base years for anomalies) are a subtle feature of data presentation.

For example, the IPCC used 1901 to 1950 as the base-year period for the surface temperature data in Figure 9.5 of their 4th Assessment Report. (See the IPCC webpage here.) At first glance, if you're familiar with surface temperature data, those base years appear to be an odd choice, because the three producers of Global Surface Temperature data don't use them. GISS uses 1951-1980 as base years, the NCDC uses 1901-2000 for graphs and 1971-2000 for maps, and the UK Met Office-Hadley Centre uses 1961-1990. Thus, for a moment you'd wonder, "Why did the IPCC use that early time period for their anomalies?" Then, it dawns on you. They used that period because 1901 to 1950 was cooler than the second half of the 20th century. Using those early base years makes the later years' data look hotter. This is illustrated in Figure 1.25-7.

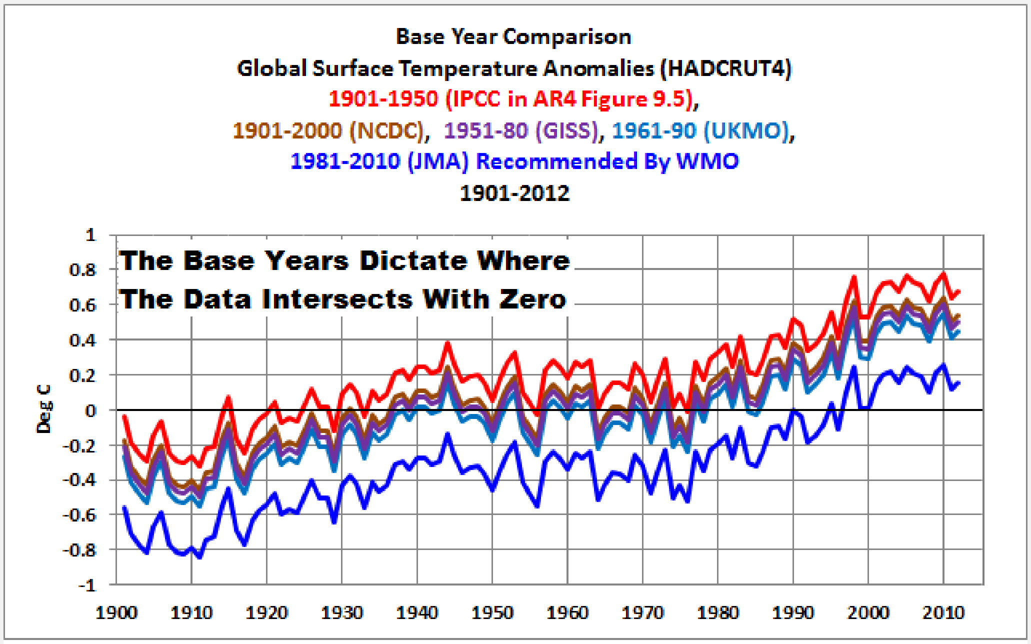


Figure 1.25-7

All of the data in Figure 1.25-7 are based on the HADCRUT4 global surface temperature data from the UK Met Office. Only the reference periods (base years) used for the anomalies are different.

Note: that I present the above for the purpose of illustration only. The UKMO HADCRUT4 data wasn't available at the time of the IPCC's AR4. They used the earlier UKMO product, HADCRUT3, in their Figure 9.5.

The IPCC's choice of 1901-1950 for base years doesn't have an impact on the shape of the curve or the warming **rate** of the data; using those early base years simply makes the data appear warmer. With respect to the base years used by the three data suppliers, the IPCC's choice of 1901-1950 shifts the data:

- about 0.14 deg C higher than it would have been using the NCDC base years,
- about 0.17 deg C higher than with the GISS base years, and
- about 0.23 deg C higher than with the UK Met Office base years.

You noticed, no doubt, that my graph in Figure 1.25-7 also includes the base years of 1981-2010. Those are the base years recommended by the WMO (World Meteorological Organization). Only one global temperature data supplier uses those recommended base years, the JMA (Japanese Meteorological Agency). Even though the WMO recommends the use of 1981-2010 for base years, GISS, NCDC, and UKMO continue to use the base years they selected for one simple reason: those base years make the data appear hotter.

Which sounds more alarming?

A. Global surface temperatures were 0.54 deg C warmer than the reference period of 1951-80

-- or --

B. Global surface temperatures were 0.16 deg C warmer than the reference period of 1981-2010

It's pretty obvious, regardless of what they claim, why GISS, NOAA and UKMO use outdated reference periods for anomalies.

DATA FOR OTHER METRICS ARE PRESENTED IN ABSOLUTE FORM AND IN ABSOLUTE FORM THEY CAN REVEAL OTHER CLIMATE MODEL FAILINGS

Unlike the combined land-ocean surface temperature products from GISS, NOAA and UKMO and ocean heat content from NOAA and UKMO, data for other metrics are available in absolute form. These include sea surface temperature, marine air temperature, precipitation, the extent and area of sea ice, the direction and speed of winds at the ocean surfaces, snow cover, sea-level pressure, Palmer Drought Severity Index, and others. Likewise, climate model outputs are in absolute form, and the outputs are available for many of those metrics. This allows us to compare models and data, not only in anomaly form, but also in absolute form.

Let's take a look at a few examples.

A model-data comparison for global precipitation anomalies is shown in Figure 1.25-8. We can see that the modeled trends are of the wrong sign. That is, the linear trend of the multi-model mean (CMIP5 models with historic and RCP8.5 forcings) shows an increase, while the trend of the satellite- and rain gauge-based precipitation data GPCP v2.2 from NOAA shows a decrease.

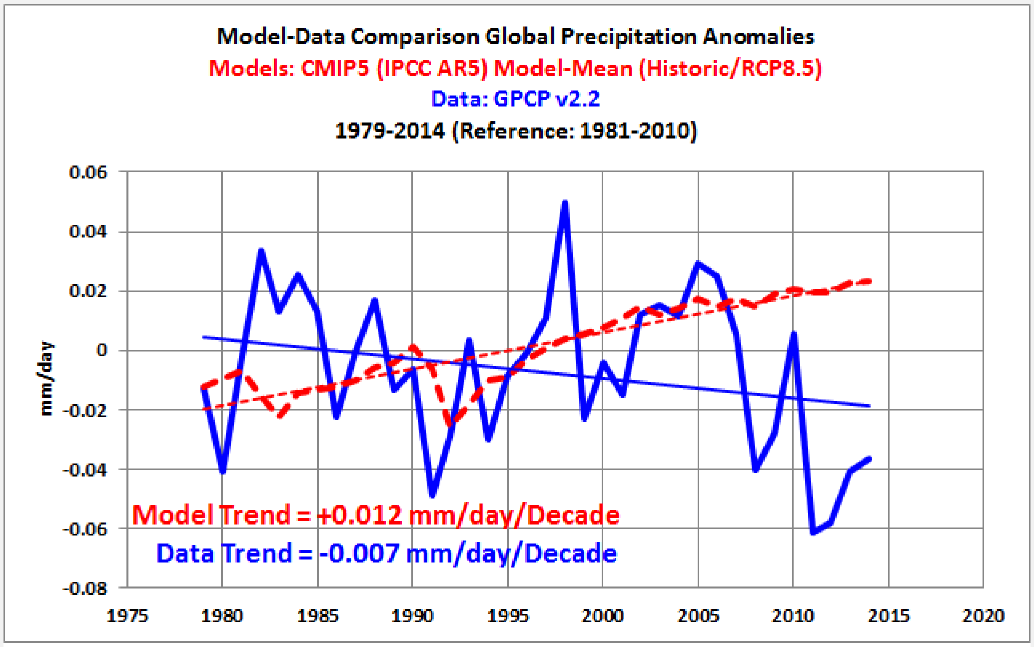


Figure 1.25-8

Unfortunately, we have no real point of reference for that graph, other than the scale of the vertical axis (y-axis), so we don't know whether those differences are really noteworthy. The span of the y-axis is only 0.14 mm/day (about 0.0055 inches/day).

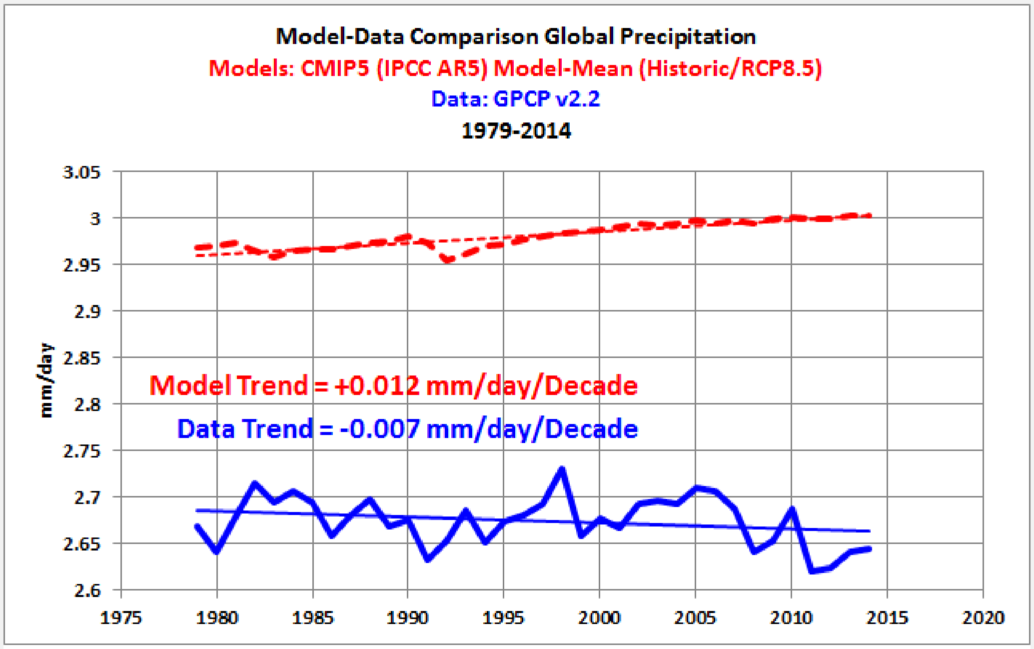


Figure 1.25-9

To really understand the differences between models and data, we need to look at them in absolute form. See Figure 1.25-9. The increase in modeled global precipitation since 1979 is about +1.4% based on the linear trend, but the satellite- and rain gauge-based data shows about a -0.9% decrease also based on the linear trend.

However, as noted in the Introduction, the big problem for the models is the amount of precipitation. The average (the consensus/groupthink) of the models are generating more than 10% too much precipitation.

Now let's put that in perspective: According to the modeled worst-case scenario (RCP8.5), global precipitation is only supposed to increase about 6% by the end of the 21st Century. See Figure 1.25-10.

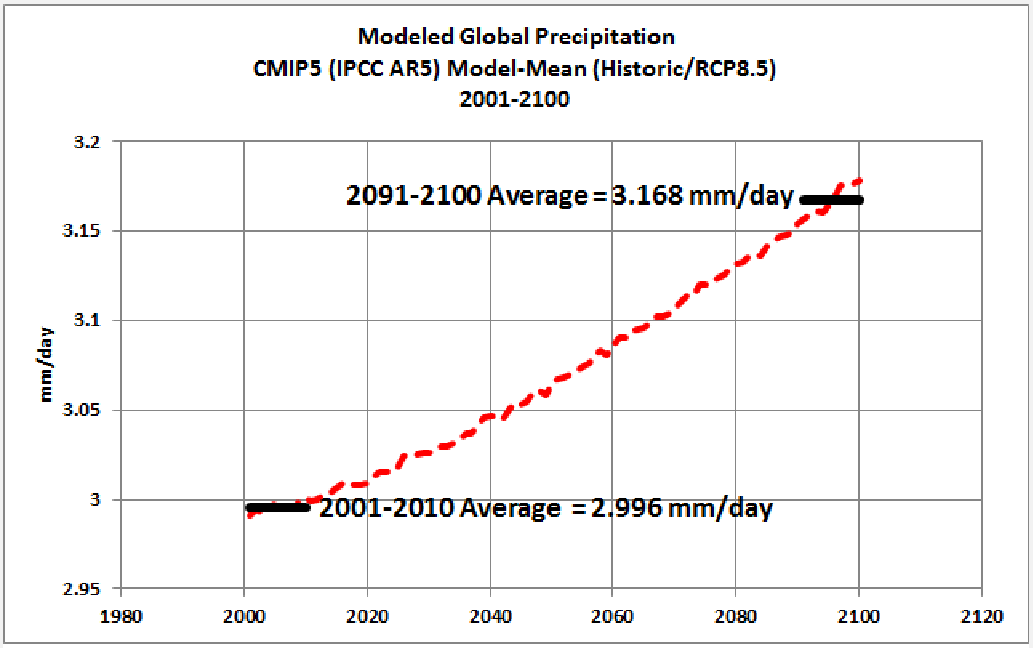


Figure 1.25-10

In other words, the difference between the modeled and observed global precipitation in recent decades (Figure 1.25-9) is greater than the expected worst-case increase by 2100 (Figure 1.25-10).

Let's look at global sea surface temperature data next. Most of those datasets are also presented in absolute form by surface temperature data suppliers. The exception to this is HADSST3 data from the UK Met Office, which are only furnished as anomalies referenced to 1961-1990. For the examples that follow, we're presenting a satellite-enhanced sea surface temperature dataset from NOAA that's commonly called Reynolds OI.v2. In their 2004 paper Improved Extended Reconstruction of SST (1854-1997), Smith and Reynolds called the Reynolds OI.v2 data "a good estimate of the truth."

First in anomaly form: see Figure 1.25-11. I've used the full term of the annual data (1982-2014) as the base years for anomalies. Looking at the values of the linear trends, we can see that the climate models (based on the multi-model mean of the CMIP5-archived models with historic and RCP6.0 forcings) almost double the observed rate of ocean surface warming over the past 33 years. Because the anomalies are referenced to the full term of the data, the trend lines intersect at the mid-point year, 1998.

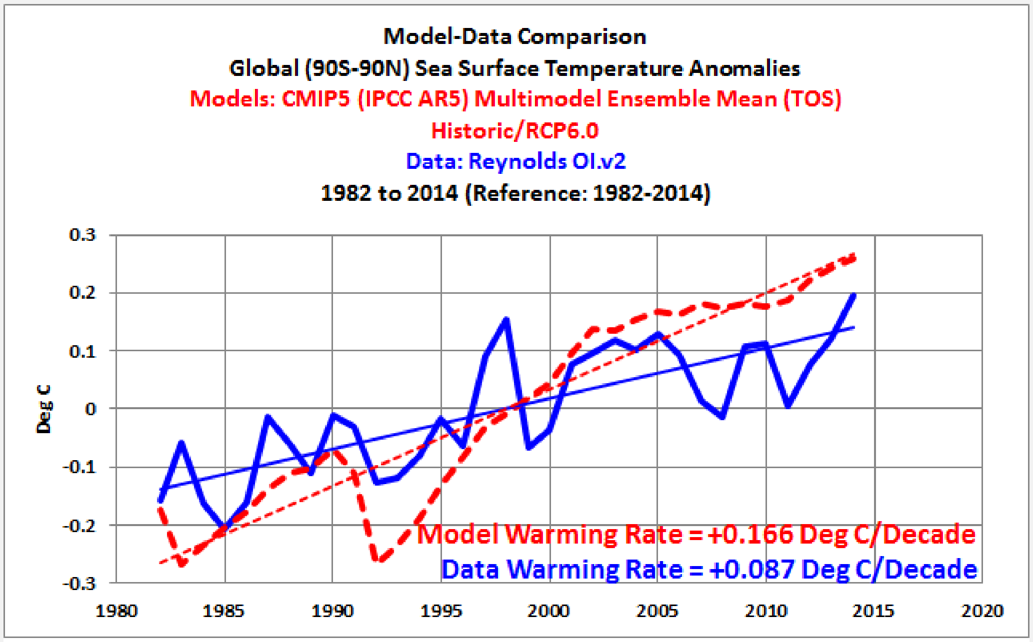


Figure 1.25-11

Let's shift the data and the model outputs so that the trend lines intersect with zero at the first year of the data, 1982. See Figure 1.25-12. This helps to highlight the tremendous differences in the warming rates between the models and observations. But because we're using anomalies, we don't know if the models are simulating ocean surfaces that are too warm or too cold.

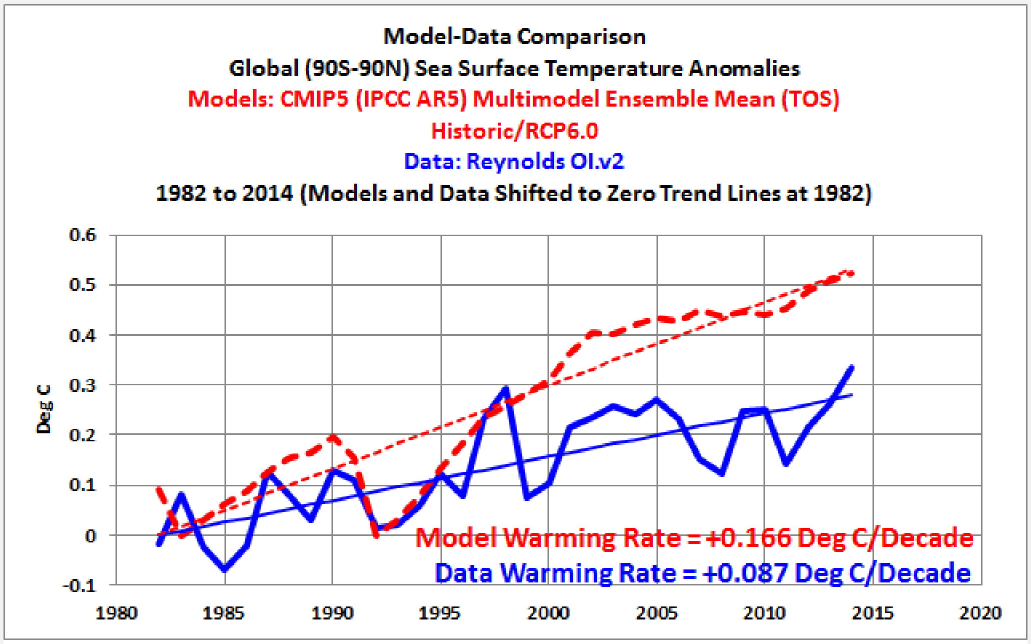


Figure 1.25-12

So in Figure 1.25-13, I've presented the modeled and observed global sea surface temperatures in absolute form.

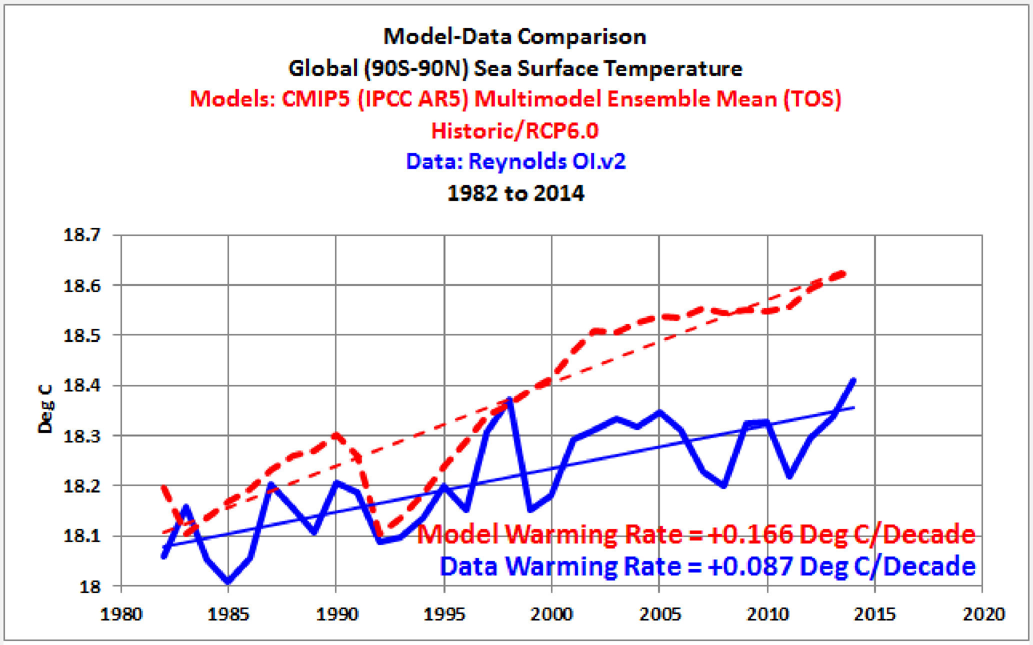


Figure 1.25-13

In absolute form, not only can we see the major disparity in the warming rates, but we can also see that the models are running too warm.

CHAPTER CLOSING

Many persons new to the discussions of global warming and climate change will complain about the use of anomalies. As discussed, there are many reasons why climate-related data are presented in anomaly form. But using anomalies in model-data comparisons can hide other model failings that are only visible when the model outputs and observations are presented in absolute form.

1.26 – A Decreasing Difference between the Daily Maximum and Minimum Temperatures (Called the DTR or Diurnal Temperature Range) is Supposed to be a Fingerprint of Man-made Global Warming

This chapter was first presented in my June 2013 blog post "Model-Data Comparison: Daily Maximum and Minimum Temperatures and Diurnal Temperature Range (DTR)". It was also cross posted at WattsUpWithThat here. It has been expanded and edited for readability in this book. This revised version was also included in my book Climate Models Fail.

CHAPTER OVERVIEW

The temperature difference between daily maximum and minimum temperatures is called the "diurnal temperature range."

Those promoting CAGW (Catastrophic Anthropogenic Global Warming) assert that the much-reported decrease in the diurnal temperature range is a "fingerprint" of human-induced global warming. As "proof," they cite climate models, of course. Then, along came the BEST (Berkeley Earth Surface Temperature) data, released to the public in October, 2011. That new dataset showed an increase in the diurnal temperature range since 1988, contradicting the models.

In this chapter, I compare the BEST dataset's daily maximum (Tmax) and minimum (Tmin) temperature anomalies with the multi-model ensemble mean of the climate models stored in the CMIP5 archive. The models did not perform well — and that's putting it nicely.

If they think there has been a decrease in diurnal temperature range and that the decrease is a "fingerprint" of human-induced global warming, climate scientists need a better Automated Fingerprint Identification System (AFIS).

INTRODUCTION

The following are examples of scientific studies whose authors blamed human-induced global warming for a narrowing of the diurnal temperature range.

Easterling, et al. (1997) "Maximum and Minimum Temperature Trends for the Globe": in an often-cited paper about the changes in the Daily Maximum (Tmax) and Minimum (Tmin) Temperatures and the daily differences between the two, the Diurnal Temperature Range (DTR), they examine data for the period of 1950 to 1993. The abstract begins:

> *Analysis of the global mean surface air temperature has shown that its increase is due, at least in part, to differential changes in daily maximum and minimum temperatures, resulting in a narrowing of the diurnal temperature range (DTR).*

Karl, et al. (1991) "Global Warming: Evidence for Asymmetric Diurnal Temperature Change" preceded Easterling, et al. The abstract in its entirety is interesting (my boldface):

> *Analyses of the year-month mean maximum and minimum surface thermometric record have now been updated and expanded to cover three large countries in the Northern Hemisphere (the contiguous United States, the Soviet Union, and the People's Republic of China). They indicate that most of the warming which has occurred in these regions over the past four decades can be attributed to an increase of mean minimum (mostly nighttime) temperatures. Mean maximum (mostly daytime) temperatures display little or no warming. In the USA and the USSR (no access to data in China) similar characteristics are also reflected in the changes of extreme seasonal temperatures, e.g., increase of extreme minimum temperatures and little or no change in extreme maximum temperatures. The continuation of increasing minimum temperatures and little overall change of the maximum leads to a decrease of the mean (and extreme) temperature range, an important measure of climate variability.*
>
> *The cause(s) of the asymmetric diurnal changes are uncertain, but there is some evidence to suggest that changes in cloud cover play a direct role (where increases in cloudiness result in reduced maximum and higher minimum temperatures). Regardless of the exact cause(s), these results imply that either: (1) climate model projections considering the expected change in the diurnal temperature range with increased levels of the greenhouse gases are underestimating (overestimating) the rise of the daily minimum (maximum) relative to the maximum (minimum), or (2)* ***the observed warming in a considerable portion of the Northern Hemisphere landmass is significantly affected by factors unrelated to an enhanced anthropogenically-induced greenhouse effect****.*

More recently, there's Braganza, et al. (2004) "Diurnal Temperature Range as an Index of Global Climate Change During the Twentieth Century." Their abstract begins (my boldface):

> *The usefulness of global-average diurnal temperature range (DTR) as an index of climate change and variability is evaluated using observations and climate model simulations representing unforced climate variability and anthropogenic climate change. On decadal timescales, modelled and observed intrinsic*

> *variability of DTR compare well and are independent of variations in global mean temperature.* ***Observed reductions in DTR over the last century are large and unlikely to be due to natural variability alone.***

For James Hansen fans, there's Hansen, et al. (2005) "Long-term Changes of the Diurnal Temperature Cycle: Implications About Mechanisms of Global Climate Change," a model-based study. This paper attributes the decrease in the diurnal temperature range to anthropogenic factors. Its abstract starts (my boldface):

> *We use a global climate model to investigate the impact of a wide range of radiative forcing and feedback mechanisms on the diurnal cycle of surface air temperature. This allows us not only to rule out many potential explanations for observed diurnal changes, but to infer fundamental information concerning the nature and location of the principal global climate forcings of this century. W****e conclude that the observed changes of the diurnal cycle result neither from natural climate variability nor a globally-distributed forcing, but rather they require the combination of a (negative) radiative forcing located primarily over continental regions together with the known globally-distributed forcing due to anthropogenic greenhouse gases.***

And, of course, there's Jones, et al. (1999) "Surface Air Temperature and Its Changes Over the Past 150 Years." Its abstract includes:

> *The twentieth-century warming has been accompanied by a decrease in those areas of the world affected by exceptionally cool temperatures and to a lesser extent by increases in areas affected by exceptionally warm temperatures. In recent decades there have been much greater increases in night minimum temperatures than in day maximum temperatures, so that over 1950–1993 the diurnal temperature range has decreased by 0.088C per decade.*

The authors of those papers could form the charter membership of a Who's Who of climate science. Just look at a few of the lead authors. The lead author of Jones et al. (1999) is Phil Jones, Director of the Climatic Research Unit of the University of East Anglia. Jones played a dominant role in Climategate. (Again, see Climategate: The Crutape Letters by Mosher and Fuller published in 2010.) James Hansen, lead author of Hansen, et al. (2005), was the head of the Goddard Institute for Space Studies in New York. Alice Bell's article in "The Guardian" "James Hansen Retires from Science to Spend More Time with His Politics" explains that Hansen intends to spend more time as a climate activist. That's not too surprising because he was an activist while he was the head of GISS. And the lead author of Karl, et al. (1991) is Thomas R. Karl, Director of NOAA's NCDC (National Climatic Data Center). The above studies, along with those of Braganza, et al. (2004), found that the diurnal temperature range was decreasing, that climate models confirmed the physics of that phenomenon, and called the decrease in the diurnal temperature range a "fingerprint" of human-induced global warming.

THE FINDINGS OF THE BEST TEAM

Then, in 2011, along came the latest and greatest land surface air temperature dataset from the BEST (Berkeley Earth Surface Temperature) team.

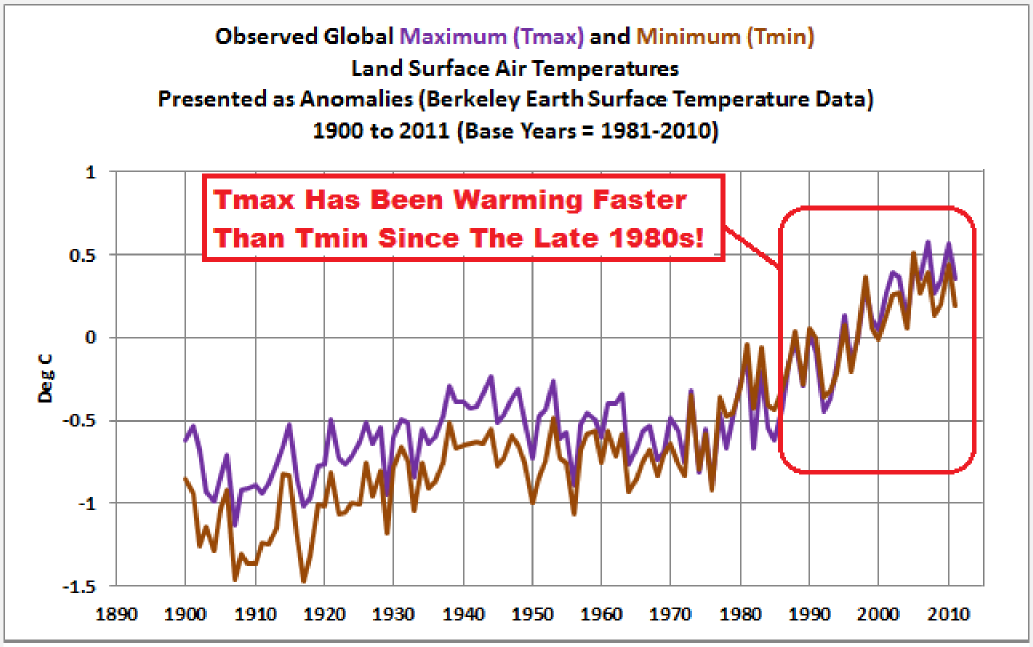


Figure 1.26-1

In Figure 1.26-1, the BEST Daily Maximum (Tmax) and Minimum (Tmin) Temperature data make it obvious that the diurnal temperature range has been **increasing** over the past 2+ decades, not decreasing. That doesn't speak too highly of the "physics" in the climate models.

The BEST team address this in their Rohde, et al. (2012) paper "A New Estimate of the Average Earth Surface Land Temperature Spanning 1753 to 2011." There, under the heading of "Diurnal Range," they write:

> *Some of the climate models predict that the diurnal temperature range, that is, the difference between Tmax and Tmin, should decrease due to greenhouse warming. The physics is that greenhouse gases have more impact at night when they absorb infrared and reduce the cooling, and that this effect is larger than the additional daytime warming. This predicted change is sometimes cited as one of the "fingerprints" that separates greenhouse warming from other effects such as solar variability. Previous studies [15-18] reported significant decreases in the diurnal temperature range over the period 1948 to 1994. Jones, et al. [18] for*

example described the decrease as 0.08°C per decade for the period 1950 to 1993.

Rohde, et al. (2012) presented the Diurnal Temperature Range in their Figure 4, which I've included here as my Figure 1.26-2.

Figure 4 from Rohde et al (2012)

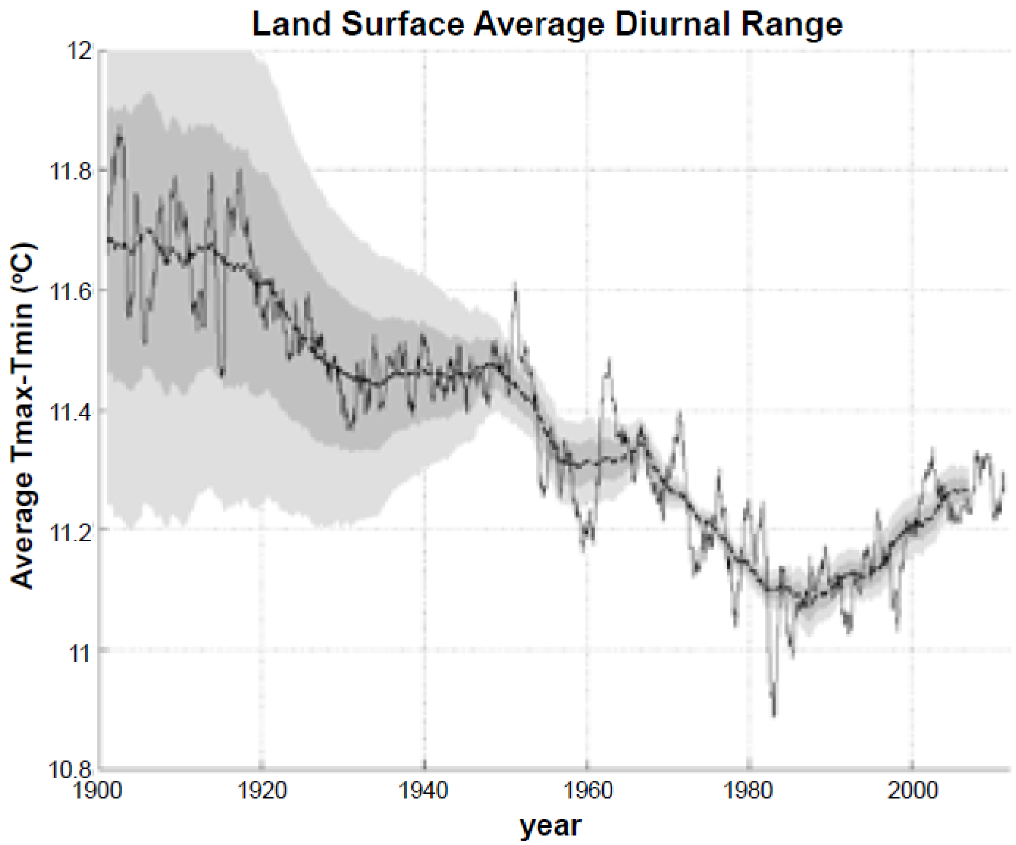


Figure 4: Earth average diurnal range, calculated from records of $D=T_{max}–T_{min}$ using the Berkeley Average estimation program. Shown are both the yearly averages and the 10-year averages, and the 1- and 2-standard deviation uncertainty estimates for the 10-year averages.

Figure 1.26-2

About their illustration, Rohde, et al. write (my boldface):

The result of this calculation is shown in figure 4. The solid line represents the annual average of the diurnal range, and the dashed line shows the 10-year running average. The 1- and 2-standard deviation error uncertainties are shown with the two grey bands for the 10-year average. The behavior of the diurnal

> *range is not simple; it drops from 1900 to 1987, and then it rises. The rise takes place during a period when, according to the IPCC report, the anthropogenic effect of global warming is evident above the background variations from natural causes.*
>
> *Although the post-1987 rise is not sufficient to undo the drop that took place from 1901 to 1987,* ***the trend of 0.86 ± 0.13°C/century is distinctly upwards with a very high level of confidence****. This reversal is particularly odd since it occurs during a period when the rise in Tavg was strong and showed no apparent changes in behavior.*

Rohde, et al. seem to be throwing a few jabs at the IPCC and the previous papers. Let's see if those jabs are deserved.

MODEL-DATA COMPARISON OVERVIEW

As noted in the overview, I compare the BEST (Berkeley Land Surface Air Temperature) data to the multi-model ensemble mean of the climate models prepared for the 5th Assessment Report of the IPCC (Intergovernmental Panel on Climate Change). Below, I compare the daily maximum and minimum temperature data and the differences between the two on a global basis. The source of the data and model outputs, once again, is the KNMI Climate Explorer where the BEST daily minimum and maximum data are presented only as anomalies, not in absolute form. As a result, I cannot present the modeled and observed diurnal temperature ranges in time-series graphs. That's fine. I will simply present instead the differences in the **trends** of modeled and observed daily maximums and minimums.

I break the comparisons into two parts, based on the dividing year identified by Rohde, et al. (2012). The first group of global data comparisons is for the period of 1988 to 2011, which is the period over which Rohde, et al. found an increase in the diurnal temperature range. (Note: 2011 is the last full year of the BEST land surface air temperature dataset.) For the second group, ending in 1987, I use the start year of 1950. I use 1950 for two reasons: 1) based on Rohde, et al.'s Figure 4 (my Figure 5-19), the data uncertainties are quite large before 1950; and 2) so that the mid-20th century cooling period would be a significant portion of the time period.

I use the WMO-recommended base years of 1981-2010 for anomalies in the time-series graphs.

I also compare the modeled and data linear trends on zonal-mean (latitude average) bases. With these trend comparisons, the fact that data are presented as anomalies becomes a moot point. As a result, I can meaningfully present the trends in the diurnal temperature ranges.

MODEL-DATA COMPARISON – TIME SERIES – 1988 TO 2011

Figure 1.26-3 is a time-series graph of the BEST global maximum and minimum temperature anomalies for the period of January, 1988 to December, 2011. My simple analysis confirms the findings of Rohde, et al. (2012). Daily maximum temperatures are warming at a faster rate than the minimums. Based on the differences in the linear trends, the diurnal temperature range increased at a rate of about 0.09 Deg C/decade from 1988 to 2011 (Rohde, et al.'s range was 0.86 ± 0.13°C/century).

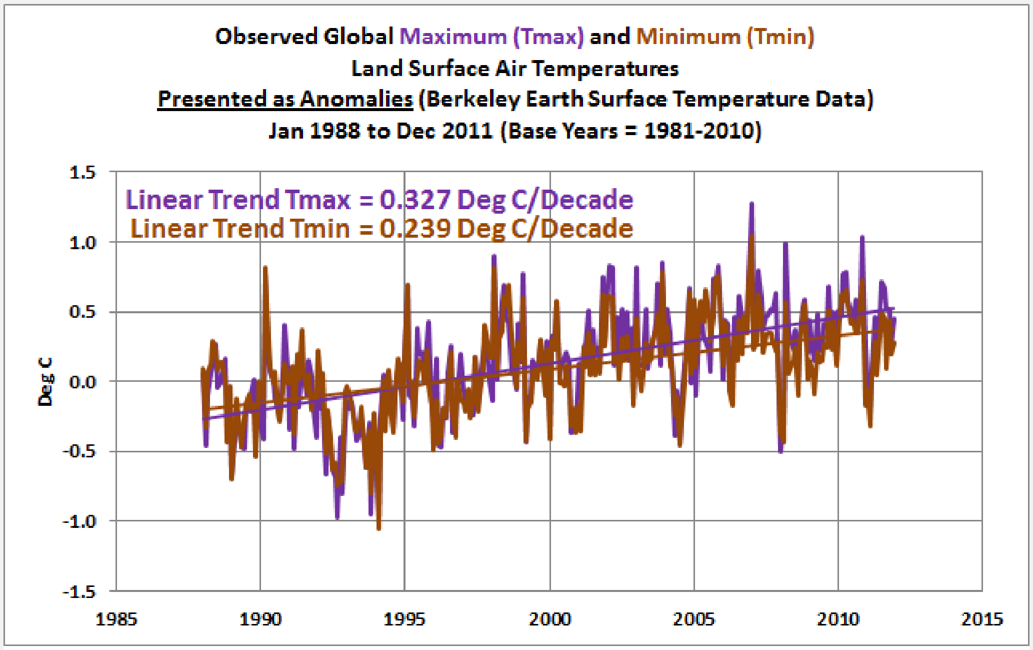


Figure 1.26-3

The multi-model mean of the CMIP5-archived models, on the other hand, estimated that the global daily minimum and maximum land surface air temperatures each warmed at basically the same rate from 1988 to 2011, with minimums warming at a slightly higher rate. See Figure 1.26-4. In other words, according to the models, if anthropogenic greenhouse gases and aerosols were the cause of the trends in the diurnal temperature range, there should have been minor decrease, when there was actually a significant increase, during this period.

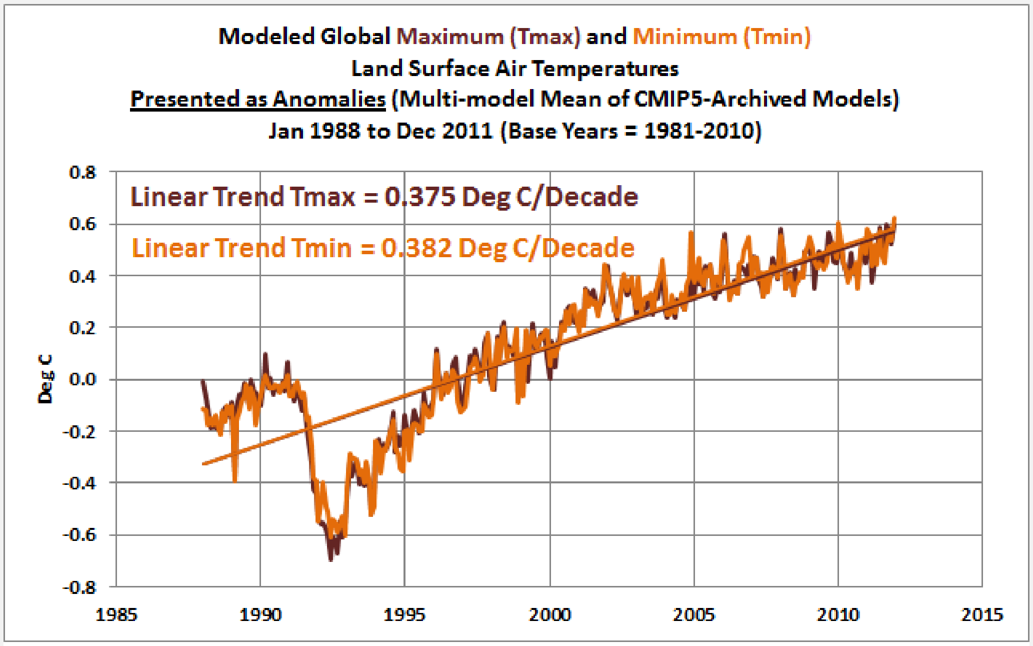


Figure 1.26-4

MODEL-DATA COMPARISON — TRENDS ON A ZONAL-MEANS BASIS — 1988 TO 2011

In the graphs under this heading, I present the global warming rates based on linear trends for the period of January, 1988 to December, 2011, using zonal-means (latitude average) graphs. Note: in the y-axis (vertical), the warming (and cooling) is scaled in deg C/Decade. The x-axis (horizontal) is scaled in degrees latitude: “-90” (90S) on the left is the South Pole; “0” is the equator; and “90” (90N) is the North Pole. In Figure 1.26-5, the model-mean output of 0.3 deg C/decade at zero latitude shows that the models estimated that the daily maximum temperatures at the equator should have warmed at a rate of 0.3 deg C per decade from 1988 to 2011.

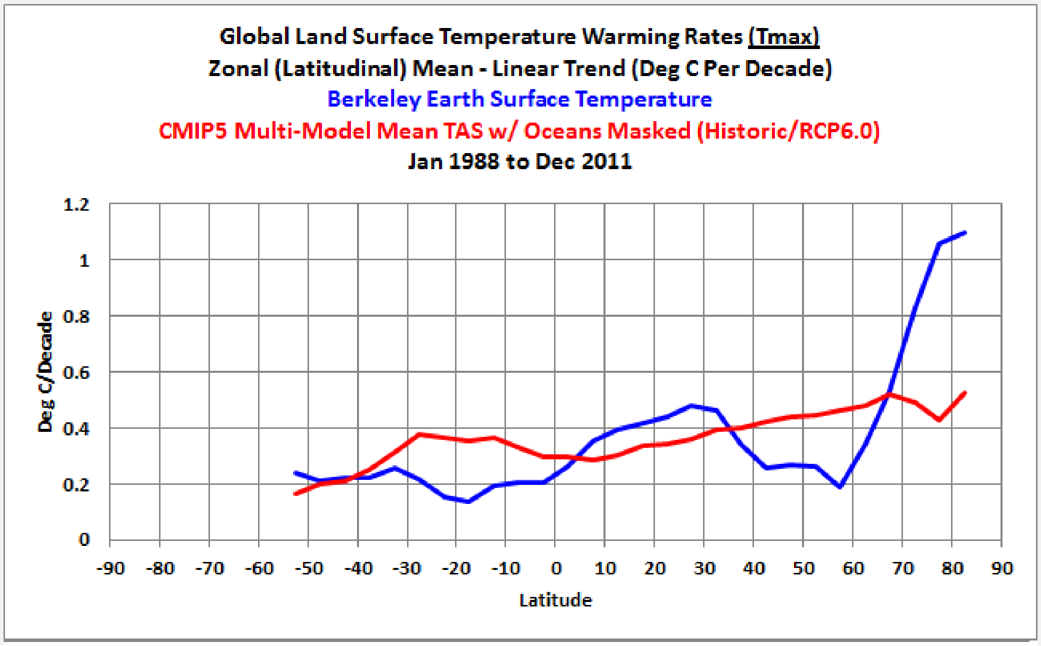


Figure 1.26-5

I'll now discuss the Figure 1.26-5 differences between the models and the observations. The models overestimated the rate of warming of daily **maximum** temperatures from about 40S to 5N and from about 35N to 65N. The models underestimated the rate of warming slightly from 5N to 35N, but **grossly underestimate the polar-amplified warming** in the Arctic (70N - 82N). Anthropogenic warming proponents continually assert that climate model projections are consistent with polar amplification data. The truth is, the multi-model mean shows ridiculously little polar amplification compared to the data. Some readers might conclude that this is another indication of flaws in the underlying physics programmed into climate models.

In Figure 1.26-6, I illustrate the modeled and observed warming rates of global daily **minimum** temperatures from 1988 to 2011. The models overestimated the warming rates of minimum temperatures from South America to the Arctic, and then, once again, completely fail to capture the polar-amplified warming in the Arctic. Note also that the observed minimum temperatures show little warming in the extra-tropics of the Southern Hemisphere. The observed warming rates of the minimums increase gradually until just north of the equator, then remain relatively constant until about 57N, where polar amplification kicks in.

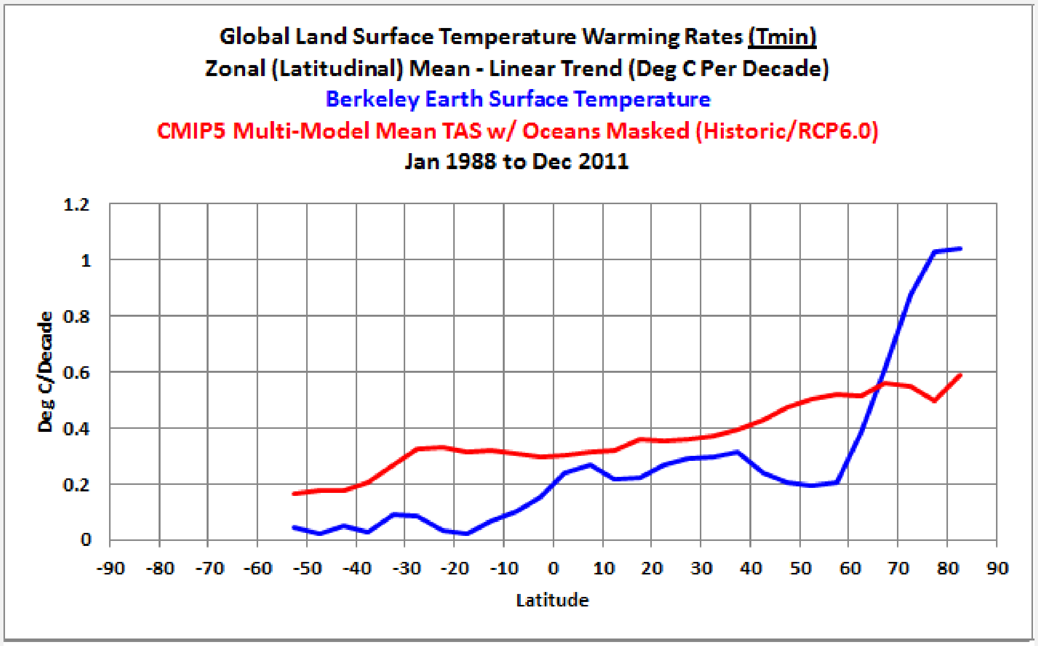


Figure 1.26-6

Figures 1.26-7 and 1.26-8 are background information for Figure 1.26-9. Figure 1.26-7 compares the **observed** warming rates in maximum and minimum temperatures from 1988 to 2011, while Figure 1.26-8 compares the **modeled** maximum and minimum warming rates.

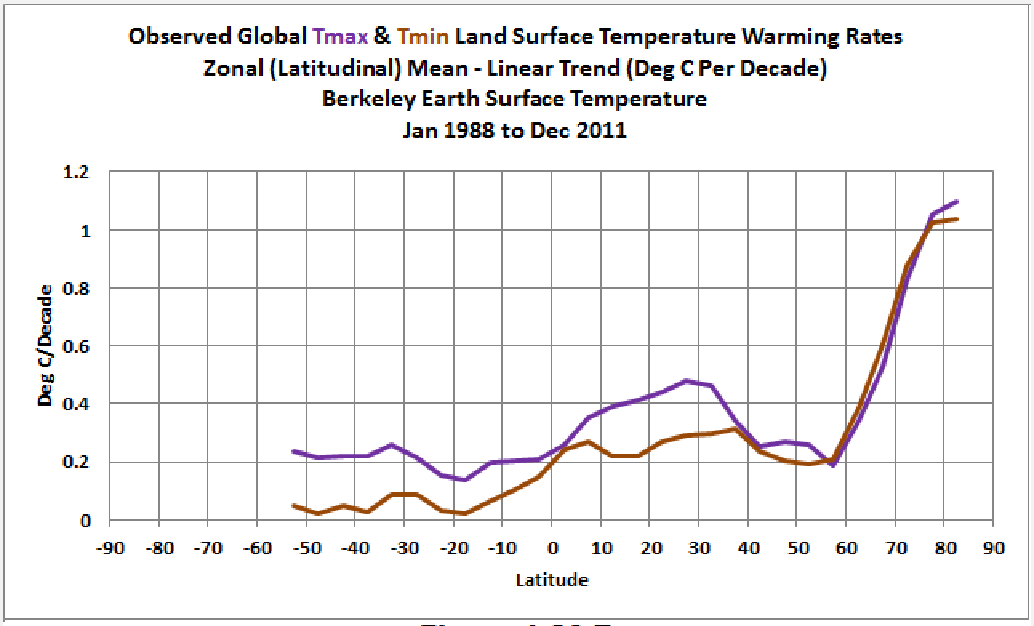


Figure 1.26-7

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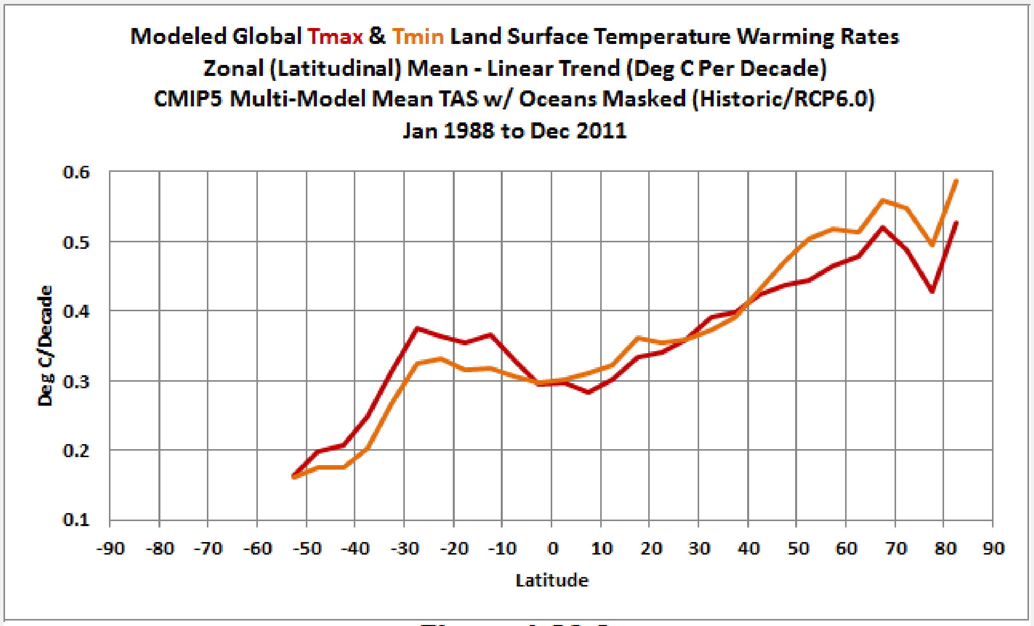

Figure 1.26-8

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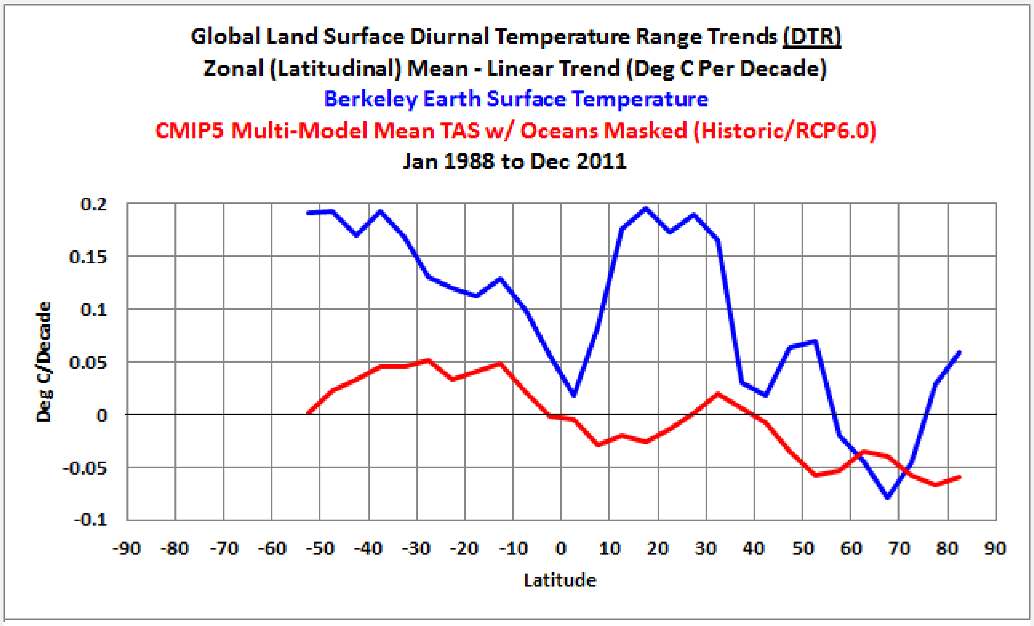

Figure 1.26-9

In Figure 1.26-9 are the observed and modeled trends in the diurnal temperature ranges on zonal-mean bases. I calculated them as the differences between the observed and modeled trends in the daily maximum and minimum temperatures. Comparing Figure 1.26-7 (actual trends) with Figure 1.26-8 (modeled trends), it is clear that the models failed to simulate the observed rates of warming. The purpose of Figure 1.26-9 is to show that trends in observed diurnal temperature ranges are not the same around the globe. Remember: a positive trend in the diurnal temperature range indicates that the maximum temperatures are warming faster than the minimums—and a negative trend in the diurnal temperature range indicates that the minimum temperatures are warming faster than the maximums.

MODEL-DATA COMPARISON – TIME SERIES – 1950 TO 1987

In Figures 1.26-10 and 1.26-11, I present the observed and modeled global daily maximum and minimum temperatures (as anomalies) for the period of 1950 to 1987. Both the models and observations show that the minimums warmed faster than the maximums. The **observations** show that the minimums warmed 0.11 deg C/Decade faster than the daily maximums. The **models**, on the other hand, show that the minimums warmed only 0.02 deg C/decade faster than the maximums. That is, the models estimated that the decrease in the diurnal temperature range (Tmax minus Tmin) would be much less than what actually happened.

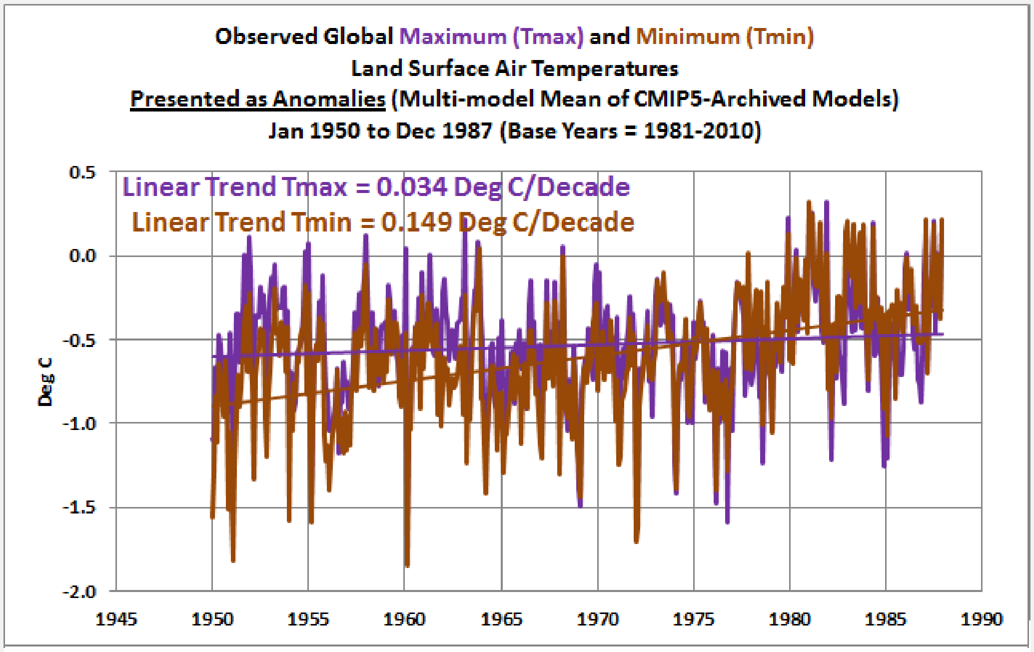

Figure 1.26-10

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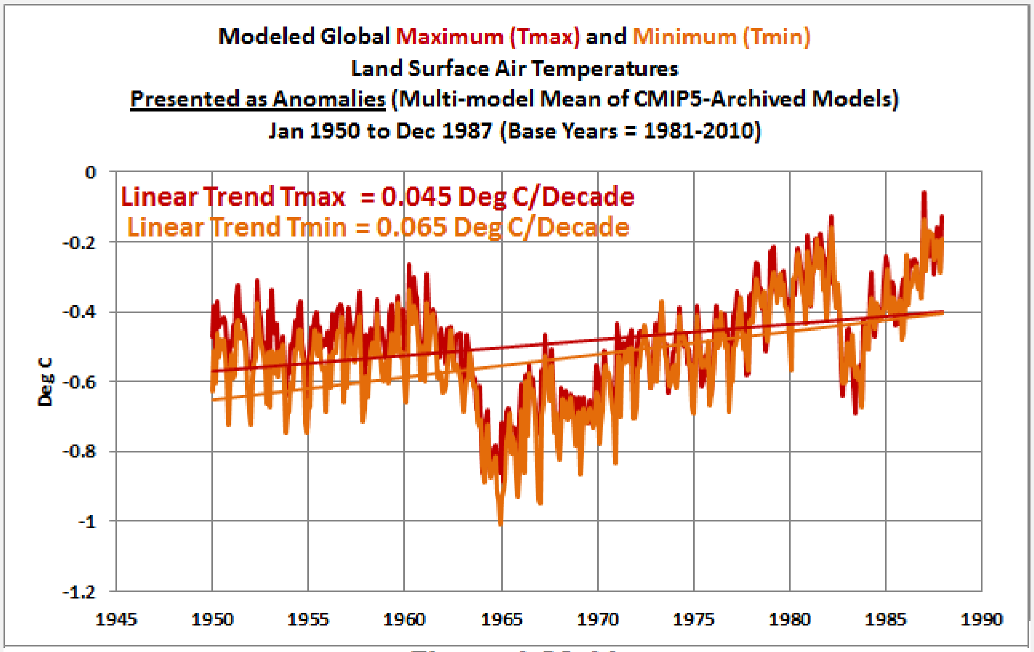

Figure 1.26-11

MODEL-DATA COMPARISON – TRENDS ON ZONAL MEAN BASIS – 1950 TO 1987

In Figure 1.26-12, I present the trends in the maximum temperatures from 1950 to 1987 on a latitudinal basis. The models performed reasonably well until the extreme high latitudes of the Northern Hemisphere, where daily maximum temperatures cooled during this period.

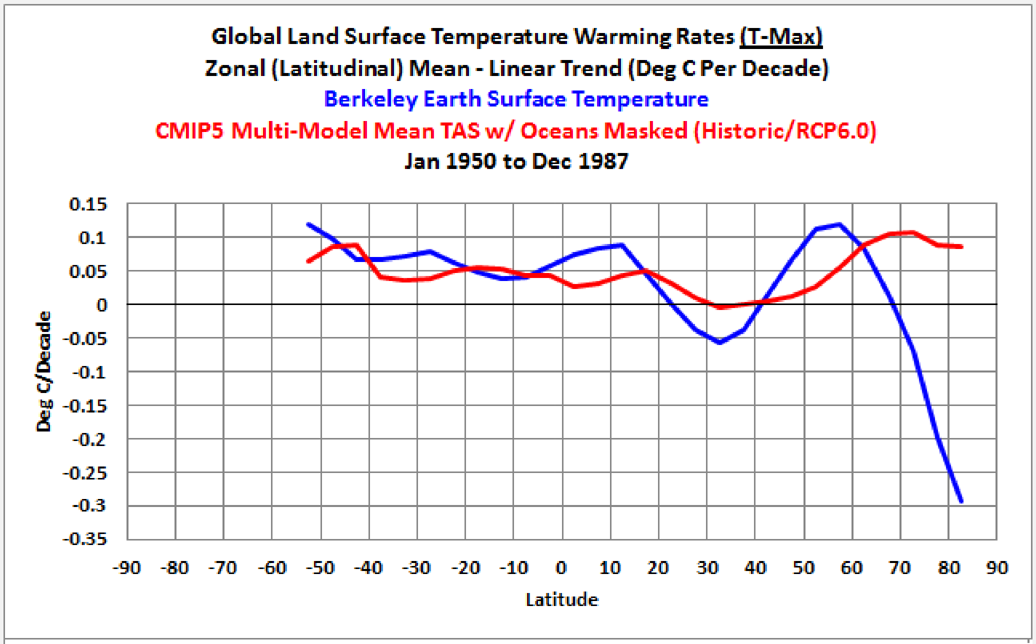

Figure 1.26-12

The modeled warming rates for the minimum temperatures from 1950 to 1987, Figure 1.26-13, were consistently lower than the observed trends — until they reach the Arctic, where, once again, observed minimum temperatures cooled drastically while the models say they should have warmed.

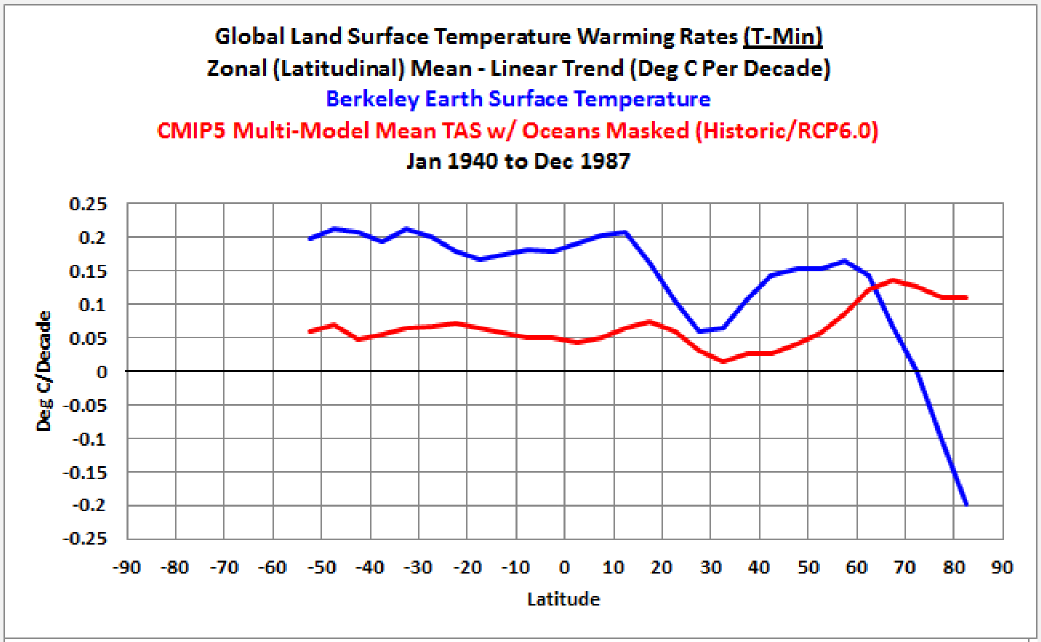

Figure 1.26-13

Figures 1.26-14 and 1.26-15 are background information for 1.26-16. Figure 1.26-14 compares the **observed** warming rates in maximum and minimum temperatures from 1950 to 1987, while Figure 1.26-15 compares the **modeled** maximum and minimum warming rates.

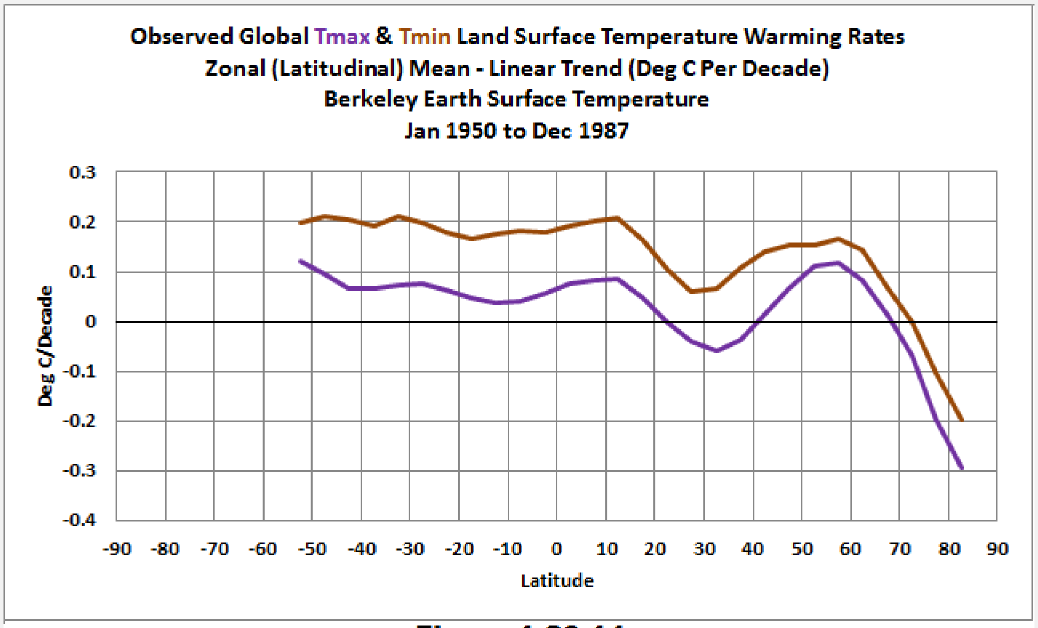

Figure 1.26-14

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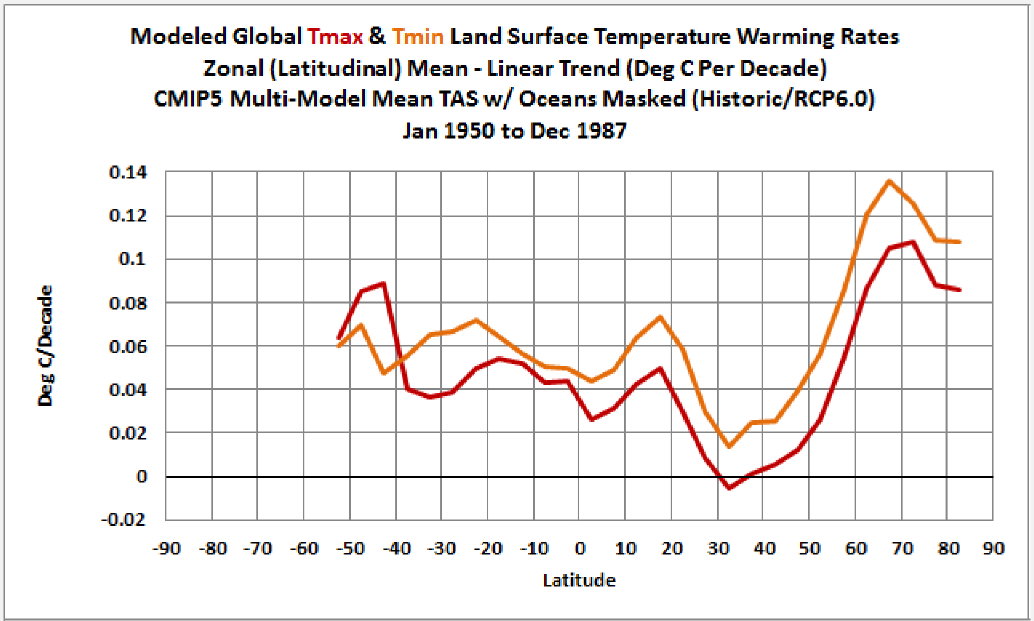


Figure 1.26-15

Figure 1.26-16 reveals the wide gap between the modeled and observed trends in global diurnal temperature range for the period of 1950 to 1987. In only one small region, at the mid-latitudes of the Northern Hemisphere, do the modeled trends in diurnal temperature range come even close to the observations.

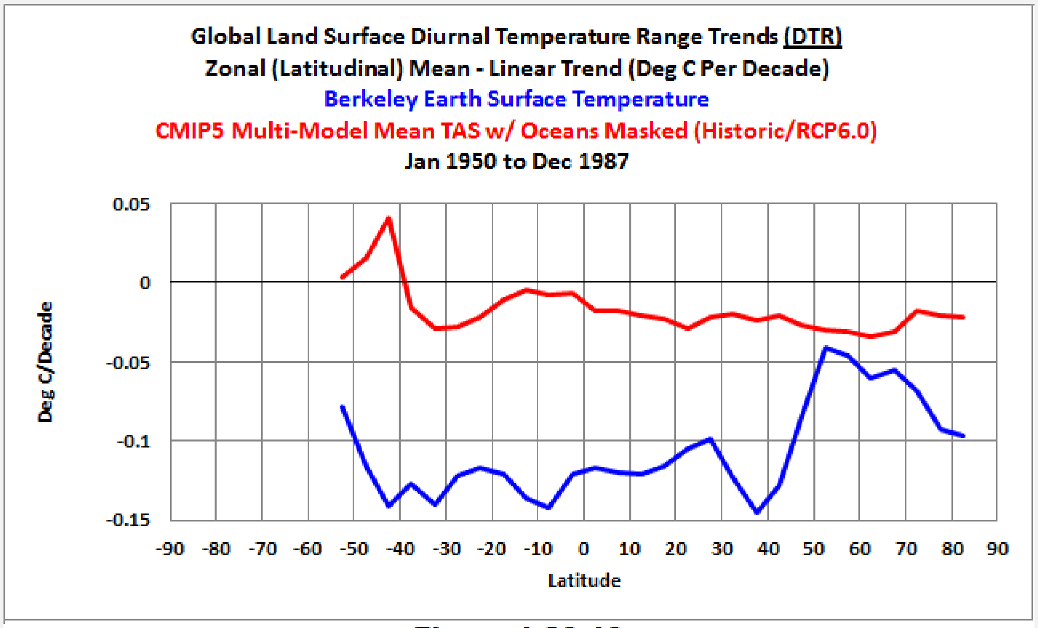


Figure 1.26-16

Finally, in Figure 1.26-17, I compare the modeled with the observed trends in global diurnal temperature ranges for the periods of 1950 to 1987 (dashed) and 1988 to 2011 (solid).

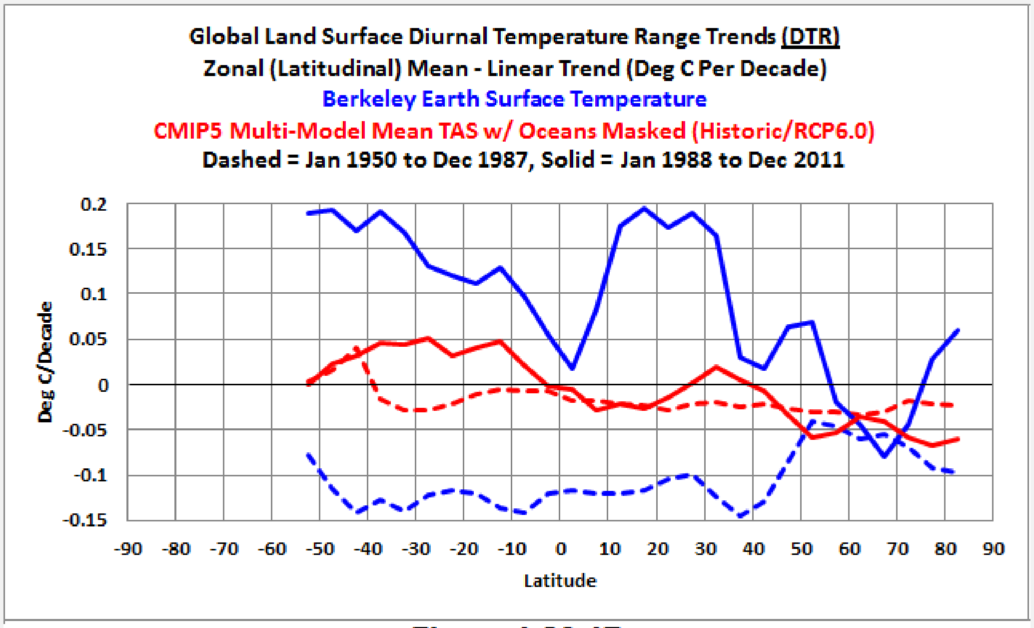


Figure 1.26-17

CHAPTER SUMMARY

For the period of 1988 to the present, climate models estimated that global daily minimum (Tmin) land surface air temperatures warmed faster than daily maximum temperatures (Tmax). This modeled decrease in the DTR (Diurnal Temperature Range) was trumpeted as being a “fingerprint” of human-induced global warming. The recently released Berkeley Earth Surface Temperature dataset show that the exact opposite happened. BEST global land surface air temperature data show Tmax warming faster than Tmin — that is, that the global diurnal temperature range since 1988 is increasing, not decreasing.

I also showed that climate models cannot simulate the observed rates of warming and cooling of global Tmin, Tmax and the DTR on latitudinal bases, for the period of 1988 to present, and for the period of 1950 to 1987.

Climate models were thus shown to be incapable of simulating what has been heralded as a “fingerprint” of human-induced global warming.

1.27 – While Surface Temperatures Are the Primary Metric Used to Describe Global Warming, Climate Scientists Are NOT Sure What That Temperature Actually Is in Absolute Form

For this discussion, I'm going to borrow a few graphs from my November 2014 post On the Elusive Absolute Global Mean Temperature – A Model-Data Comparison.

The three primary suppliers of reconstructed global surface temperature products—Goddard Institute of Space Studies (GISS), NOAA and the UK Met Office (UKMO)—and newcomer Berkeley Earth (BEST) furnish their global surface temperature data in anomaly form. Anomalies are deviations from "normals", and of course the three primary suppliers use different multidecadal base periods for their "normals". We discussed the reasons for this in Chapter 1.25. GISS, NOAA and Berkeley Earth also provide estimates of Earth's absolute surface temperature during their chosen base periods. By adding those estimates to their surface temperature anomalies those products can be displayed in absolute form. (See the GISS webpage here, NOAA here and Berkeley Earth here for their estimates of Earth's surface temperatures.)

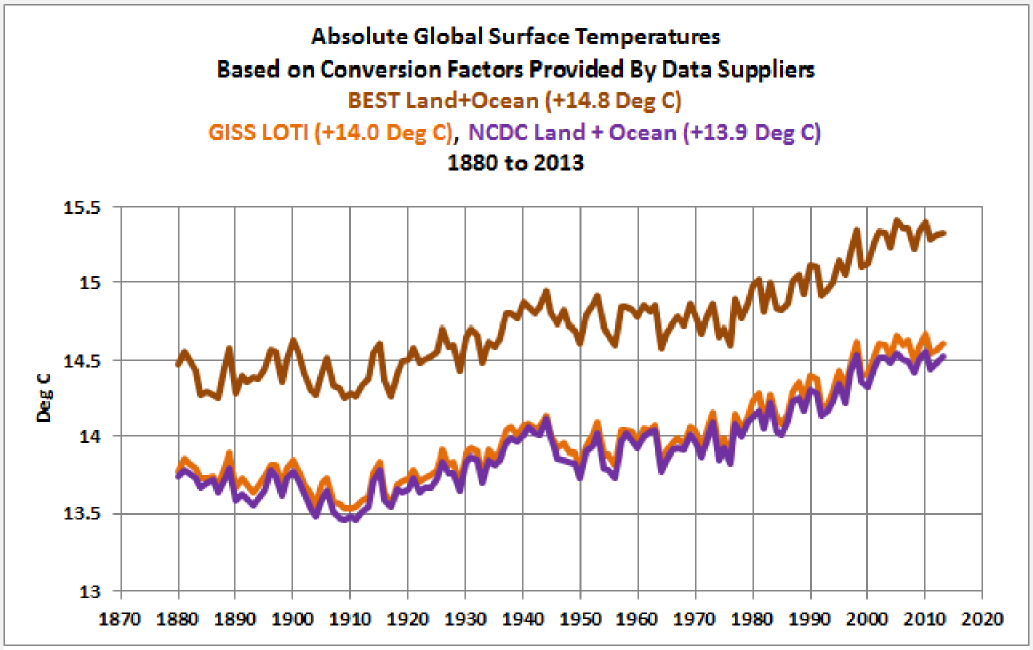


Figure 1.27-1

Figure 1.27-1 illustrates the GISS, NOAA and Berkeley Earth estimates of absolute global surface temperatures for the period of 1880 to 2013. For most of the term, the BEST data in absolute terms is about 0.8 deg C (about 1.4 deg F) warmer than the NOAA/NCDC (now called NOAA/NCEI) estimate.

Let's put that in perspective. The 0.8 deg C difference between the NOAA/NCDC and Berkeley Earth estimates of global surface temperatures is about the same as all of the warming that's taken place from 1880 to 2013, based on the linear trend of the Berkeley Earth (BEST) data, which have the highest warming rate. See Figure 1.27-2.

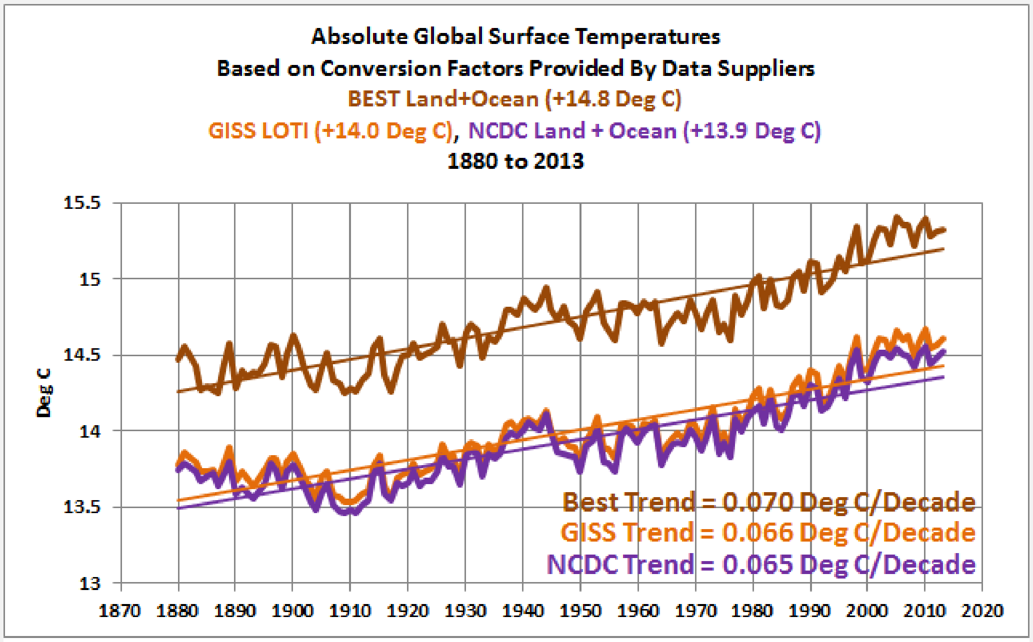


Figure 1.27-2

One more thing to consider: the uncertainties in the estimates of absolute global mean surface temperatures. This was briefly mentioned in Jones et al. (1999) Surface air temperature and its changes over the past 150 years. They write:

> New et al. [1999] have estimated cross-validation errors for their climatology over large regional land areas. Typical errors are in the range 0.5 deg-1.0 deg C, the larger values occurring over either data sparse regions or areas with complex terrain. Because there are potentially greater errors in our climatology over the Southern Ocean and Antarctica, due to sparse and incomplete (with respect to 1961-1990) data and the slightly different Arctic Ocean base period, we have not attempted to estimate standard errors for the climatology. Comparison with the earlier climatologies suggests that the value of 14 deg C is within 0.5 deg C of the true value.

In other words, Jones et al. didn't calculate the uncertainties due to the poor spatial coverage of the observations, so they are basically guessing that the global surface temperatures for the period of 1961-1990 are 14.0 deg C +/- 0.5 deg C (57.2 deg F +/- 0.9 deg F).

THE ESTIMATES OF EARTH'S ABSOLUTE SURFACE TEMPERATURE COVER AN EVEN WIDER RANGE IN CLIMATE MODELS

The following graphs include (or are based on) the 81 individual climate model simulations of global mean surface temperature from 39 climate models stored in the CMIP5 archive, using the historic and RCP8.5 forcing scenarios. As we've discussed numerous times throughout this book, the outputs of the climate models used by the IPCC for their 5th Assessment Report are stored in the Climate Model Intercomparison Project Phase 5 (CMIP5) archive, and those outputs are publically available to download in easy-to-use formats through the KNMI Climate Explorer. The CMIP5 surface air temperature outputs at the KNMI Climate Explorer can be found at the Monthly CMIP5 scenario runs webpage and are identified as "TAS".

The model outputs at the KNMI Climate Explorer are available for the historic forcings with transitions to the different future RCP scenarios. (See Chapter 2.4 – Emissions Scenarios.) For this chapter, we're presenting the historic and the worst-case future scenario, RCP8.5. We're using the worst case scenario solely as a reference for how high surface temperatures could become, according to the models, if emissions of greenhouse gases rise as projected by the models under that scenario. The use of the worst case scenario will have little impact on the model-data comparisons from 1880 to 2013. As you'll recall, the future scenarios start for most models after 2005, others start later, so there's very little difference between the model outputs for the different model scenarios in the first few years of the projections. Also, for this chapter, I downloaded the outputs separately for all of the individual models and their ensemble members.

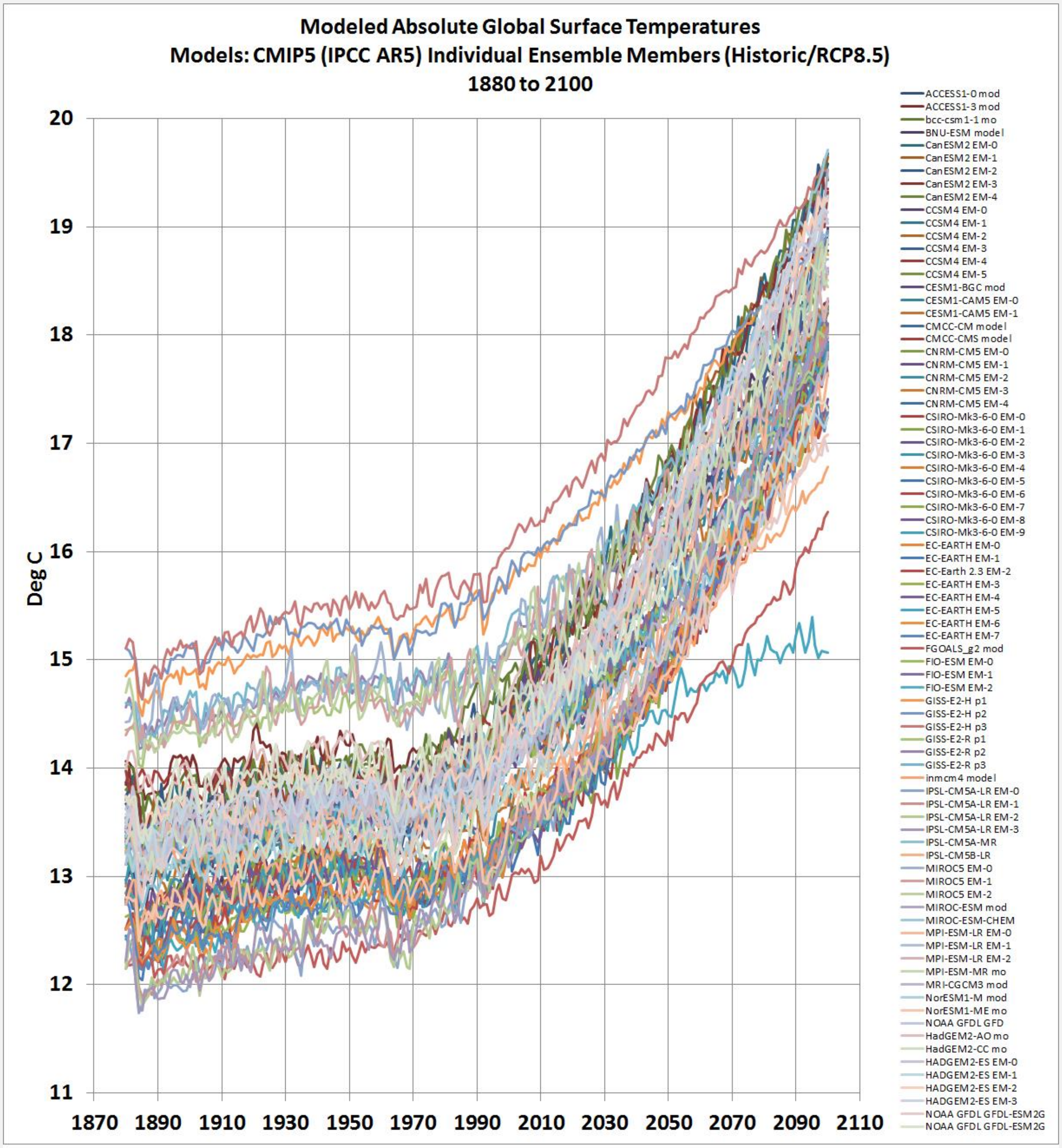


Figure 1.27-3

With that as background, Figure 1.27-3 is a spaghetti graph showing the CMIP5-archived outputs of the climate model simulations of global surface air temperatures from 1880 to 2100, with historic and RCP8.5 forcings. Whatever the global mean surface temperature is now, or was in the past, or might be in the future, the climate models use by the IPCC for their 5th Assessment Report certainly have those values surrounded. See Figure 1.27-4, in which I've added the BEST and NOAA surface temperature data in absolute forms.

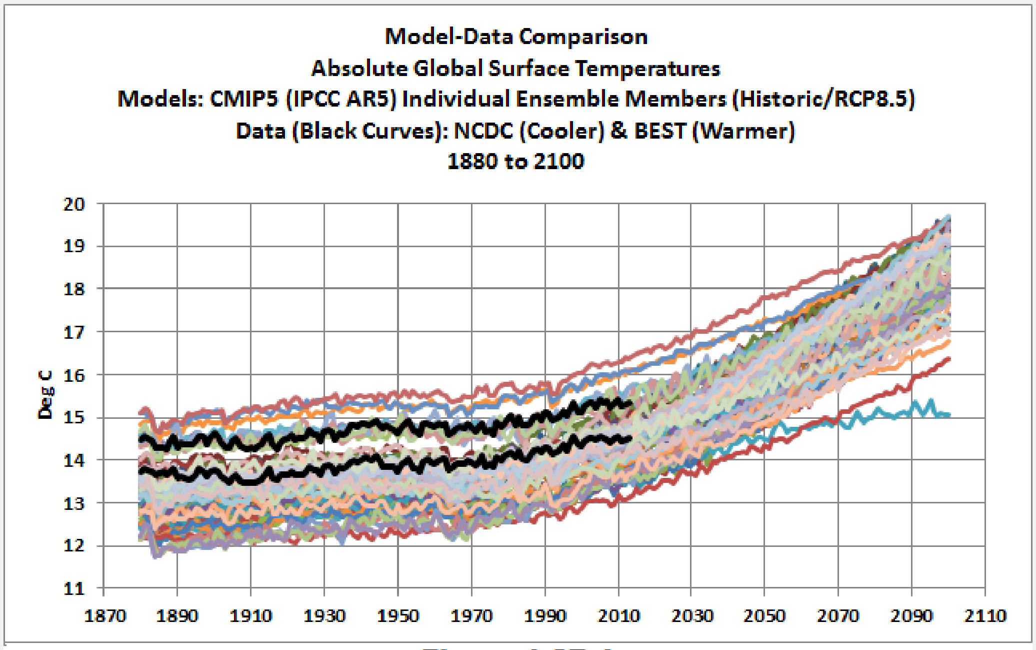


Figure 1.27-4

Some people might want to argue that absolute temperatures are unimportant—that we're concerned about the past and future rates of warming. We can counter that argument a few ways: First, we've already seen and we'll continue to present how poorly climate models simulate surface temperature anomalies from 1880 to present and from the 1980s to present. Absolute temperatures are important for other reasons. Natural and enhanced greenhouse effects depend on the infrared radiation emitted from Earth's surface, and the amount of infrared radiation emitted to space by our planet is a function of its absolute surface temperature, not anomalies. Additionally, the actual surface temperature of Earth's surface should dictate how much water vapor is in the atmosphere. We've discussed how climate modelers need water vapor to provide positive feedback to global warming, in order to enhance the warming so that it's assumed to be "dangerous". In other words, models with higher surface temperatures should have more moisture in the air and should be more sensitive to the forcings from man-made greenhouse gases. Conversely, models with lower surface temperatures should have less moisture in the air and should be less sensitive to man-made greenhouse gases. We'll discuss in a few moments how that is not the case with the models.

Looking again at the broad range of model simulations of global mean surface temperatures in Figure 1.27-3 and 1.27-4 above, there appears to be at least a 3 deg C (5.4 deg F) span between the coolest and the warmest. Let's confirm that.

For Figure 1.27-5, I've subtracted the coolest modeled global mean temperature from the warmest in each year, from 1880 to 2100. For most of the period between 1880 and

2030, the span from the coolest to the warmest modeled surface temperature is greater than 3 deg C (5.4 deg F).

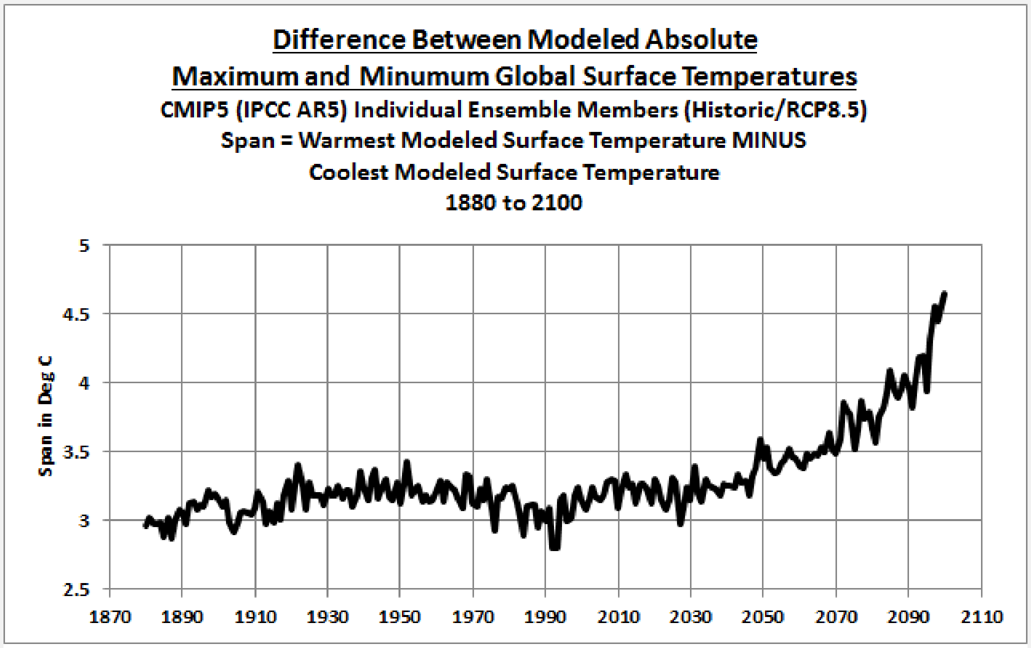


Figure 1.27-5

Yet, politicians are trying to limit greenhouse gases so that global surface temperatures don't warm more than 2.0 deg C (3.6 deg F) above pre-industrial values.

Later in the book, we'll return to the discussions in the post On the Elusive Absolute Global Mean Temperature – A Model-Data Comparison. But regarding that post, let's examine some…

…**MISDIRECTION FROM THE CLIMATE SCIENCE COMMUNITY**

About a month after I published the November 2014 post On the Elusive Absolute Global Mean Temperature – A Model-Data Comparison, the climate science community published a blog post on the same subject. Because that blog post by Dr. Gavin Schmidt (Director of GISS) didn't refer to my post, I can't really say it's a rebuttal. Regardless, the related December 2014 post by Dr. Schmidt at RealClimate was Absolute temperatures and relative anomalies. It includes a couple of very interesting comments.

First, Dr. Schmidt writes, where GMT is global mean temperature (my boldface and my brackets):

> *Most scientific discussions implicitly assume that these differences [in modeled absolute global surface temperatures] aren't important i.e. the changes in temperature are robust to errors in the base GMT value, which is true, and*

> *perhaps more importantly, are focussed on the change of temperature anyway, since that is what impacts will be tied to.* ***To be clear, no particular absolute global temperature provides a risk to society, it is the change in temperature compared to what we've been used to that matters****.*

Interesting. "…it is the change in temperature compared to what we've been used to that matters." Ponder that "…what we've been used to…" for a moment. The IPCC assumes most of the global warming since 1950 is attributable to mankind. That warming, based on the linear trend from 1950 to 2014 is about 0.72 deg C (about 1.3 deg F). Yet the surface temperatures at my home today are expected to vary 17 deg C (about 30 deg F). That is, I'm "used to" a daily variation in daily temperature that's much greater than the global warming since 1950. I'm also "used to" temperatures in winter reaching minimums that are about 50 deg C (90 deg F) colder than maximums in summer. A change in global mean temperature of 0.72 deg C (about 1.3 deg F) over the 65 years doesn't register in what I'm "used to". The thermostat on my wall has a wider deadband than 0.7 deg C.

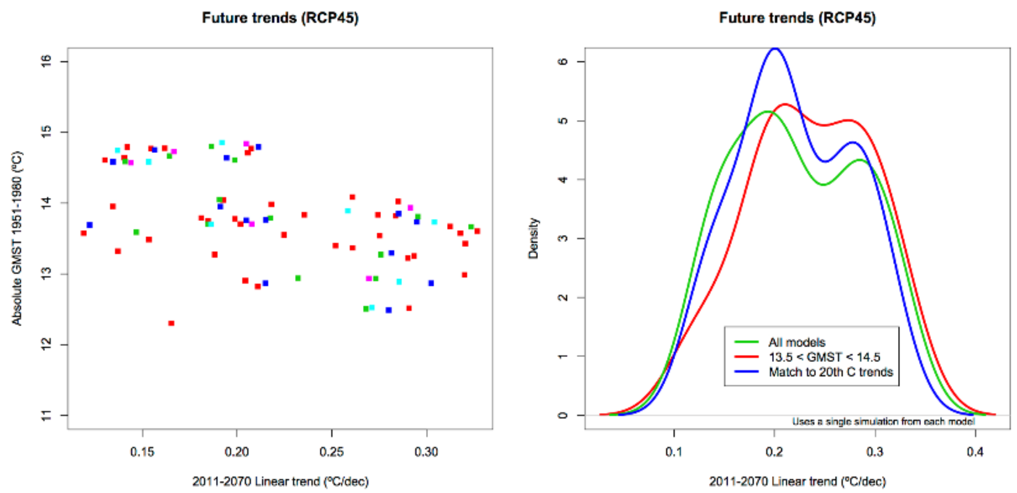
Every generation becomes "used to" the ever changing weather where they live. Sometimes in some places there are droughts, other times in those same places there are floods. Climate is always changing. People living in developed nations are better at adapting to change than those in developing nations.

Many of the topics of Dr. Schmidt's post are attempts to explain why modeled absolute temperatures are not important. One statement and graph that caught my eye was:

> *The next figure shows that the long term trends in temperature under the same scenario (in this case RCP45) are not simply correlated to the mean global temperature, and so, unsurprisingly, looking at the future trends from only the models that do well on the absolute mean doesn't change very much…*

My Figure 1.27-6 is the graph referred to by Dr. Schmidt. The graph on the left shows the correlation between modeled absolute temperatures and the warming rates (trends) in global surface temperatures from 2011-2070, using the models in the CMIP5 archive with RCP4.5 scenario forcings. Contrary to what Dr. Schmidt has written, notice how, as the absolute temperatures of the models decrease, there is an increase in the warming rate of the models. In other words, models with cooler global mean temperatures show global warming increasing at faster rates than models with warmer global surface temperatures. That is the opposite of what is expected if water vapor provided positive feedback, as we've been told. Let's expand on that.

Illustration from Dr. Schmidt's Blog Post *Absolute temperatures and relative anomalies*



A) Correlation of absolute temperatures with trends in the future across the CMIP5 ensemble. Different colors are for different ensemble members (red is #1, blue is #2, etc.). B) Distribution of trends to 2070 based on different subsets of the models segregated by absolute temperatures or 20th Century trends.

Source: http://www.realclimate.org/index.php/archives/2014/12/absolute-temperatures-and-relative-anomalies/

Figure 1.27-6

Water vapor in the atmosphere should be higher in the warmer models, if the models were simulating climate as it exists on Earth. And if water vapor provides positive feedback, as climate scientists insist, then the models with the higher surface temperatures (and higher water vapor) should have faster warming rates. But they don’t; they have slower warming rates, the opposite of what’s expected according to the climate science groupthink.

CHAPTER CLOSING

While politicians meet annually to devise treaties intended to limit greenhouse gases, scientists don’t know the actual surface temperature of the Earth. The range of moldeled absolute surface temperatures is more than three times the warming that has taken place since 1880.

Also, very oddly, climate models with warmer surface temperatures show warming that is slower than those models with cooler surface temperatures, which is the opposite of what would be expect in the real world.

GENERAL DISCUSSION 2

On the Claims of Record-High Global Surface Temperatures in 2014

Mainstream media tend to ignore the uncertainties of global surface temperature data when suppliers of that data, like NOAA's National Centers for Environmental Information (NCEI) and NASA's Goddard Institute for Space Studies (GISS), hold annual press conferences to present their findings. So we might be told that global temperatures are at record highs when the uncertainties of the data show the scientists don't know for sure which year is warmest. This happened early in 2015 with the 2014 annual report on global temperatures. Even more disturbing is that those scientists, and in turn the mainstream media, failed to disclose the natural cause of those supposed record highs.

Like the tack taken by the mainstream media, this not a discussion of data uncertainties so we'll ignore them as well. I did, however, discuss those uncertainties in the post NASA GISS & NOAA NCDC Need to Be More Open with the Public when Making Proclamations about Global Warming Records.

This is also not a discussion of long-term trends. This is simply a presentation of which ocean basin showed record high surface temperatures in 2014 and why they were at those high levels.

In General Discussion 3, we'll do the same for 2015 (year to date) and show from past records, that we may be in store for more claims of record highs in 2016.

FIRST THINGS FIRST – LET'S GET SOMETHING OUT OF THE WAY

This is a discussion of surface temperatures, not lower troposphere temperatures.

Lower troposphere temperature data are not derived from measurements at the surface. They are calculated from satellite observations of the radiance of the atmosphere at various wavelengths, at various heights above sea level. And as is plainly visible in the graphs of surface temperature and lower troposphere temperature data in Figure GD-2-1, global lower troposphere temperature data were not near record high levels in 2014. On the other hand, surface temperature data did show record highs in 2014.

I've used the average of the surface temperature data from the three primary suppliers (NASA/GISS, NOAA/NCEI and UKMO) in Figure GD-2-1 (top graph), along with the average of the two sources of lower troposphere temperature data (RSS and UAH) for the bottom graph. Both graphs run from 1995 to 2014, giving 2 decades of data. The horizontal lines are the 2014 (blue) values. So, yes, we know that 2014 was not a record-high year for lower troposphere temperatures, but this is a discussion of surface temperature data.

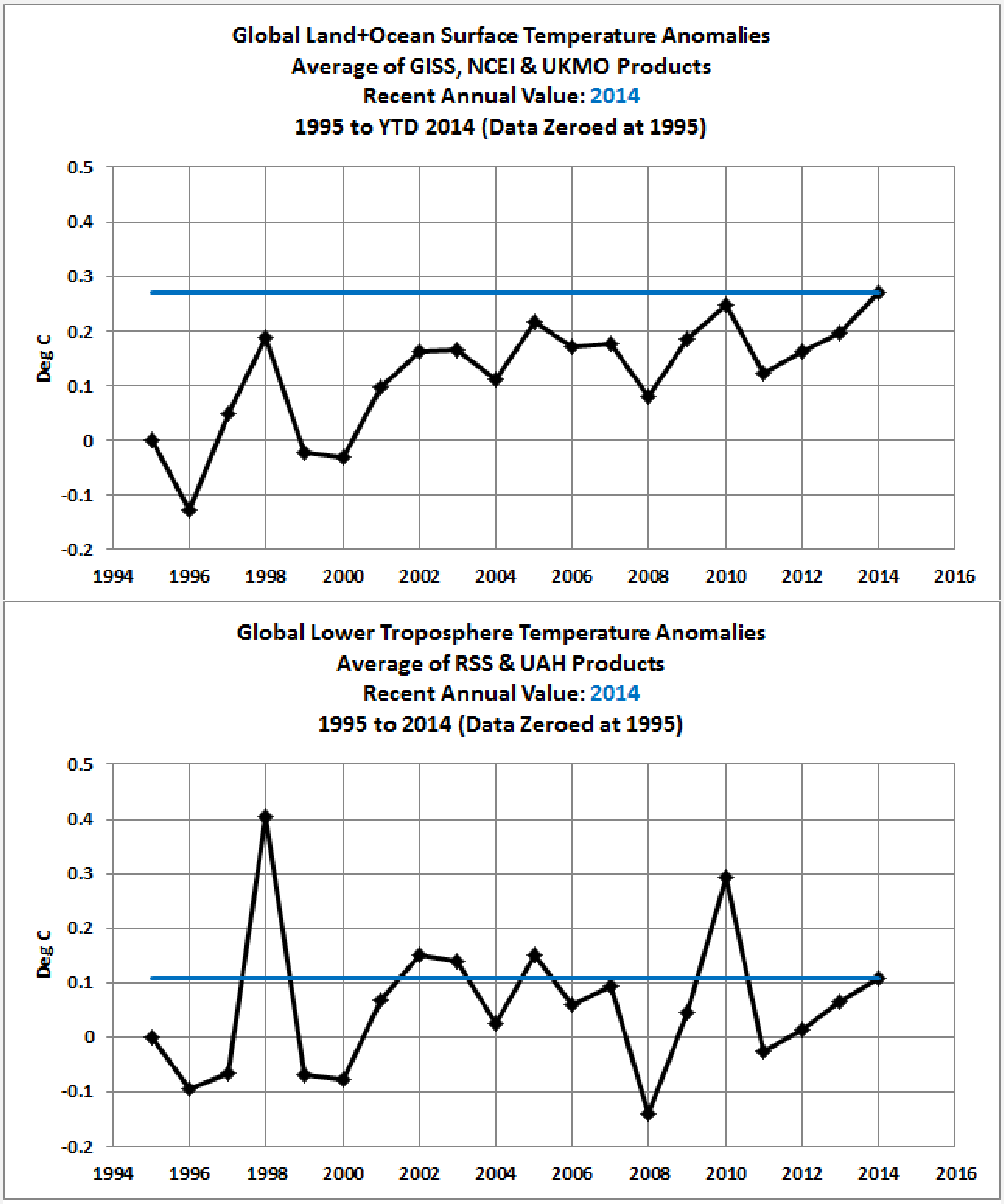


Figure GD-2-1

Note: The data in all of the annual graphs in this chapter have been shifted so that the values are zero in 1995, their start year. That doesn't change the shape of the curves or their warming rates. It simply serves as a common reference point for the changes in temperature over the past 2 decades. The start year of 1995 was chosen for a number of reasons. It provides 2 decades of data for much of this discussion. An ocean basin showed no warming for 19 years, starting in 1995, before an unusual warming event ended that absence of warming. 1995 is also 4 years after the 1991 eruption of Mount

Pinatubo, so there should be little impact of that eruption on data and model trends. It's also a couple of years before the 1997/98 El Niño, which should cut down on the claims that I've cherry-picked that start year [End note.]

An explanation for the additional volatility of the lower troposphere temperature data: Strong El Niño events impact the lower troposphere in two ways. First, the lower troposphere warms in response to the warming at the surface caused by the strong El Niño…not only in the tropical Pacific but globally as well. Second, most of the heat released from the tropical Pacific during an El Niño is caused by an increase in evaporation. There is simply more evaporation taking place in the tropical Pacific during the El Niño because of the (naturally) warmer-than-normal surface waters caused by the El Niño. That warm and moist air rises into the atmosphere, and as it rises, it cools, because the atmosphere grows colder with altitude. Eventually, the moisture in the rising air condenses and forms clouds, and when the moisture condenses (changes state) it releases heat (latent heat) to the troposphere. So the lower troposphere is warmed in two ways during a strong El Niño.

LAND SURFACE AIR TEMPERATURES WERE NOT AT RECORD HIGHS IN 2014

As shown in Figure GD-2-2, none of the primary suppliers of land surface air temperature data were able to claim that the surface air temperatures over land were at record high levels in 2014. And as far as I know, none of them did.

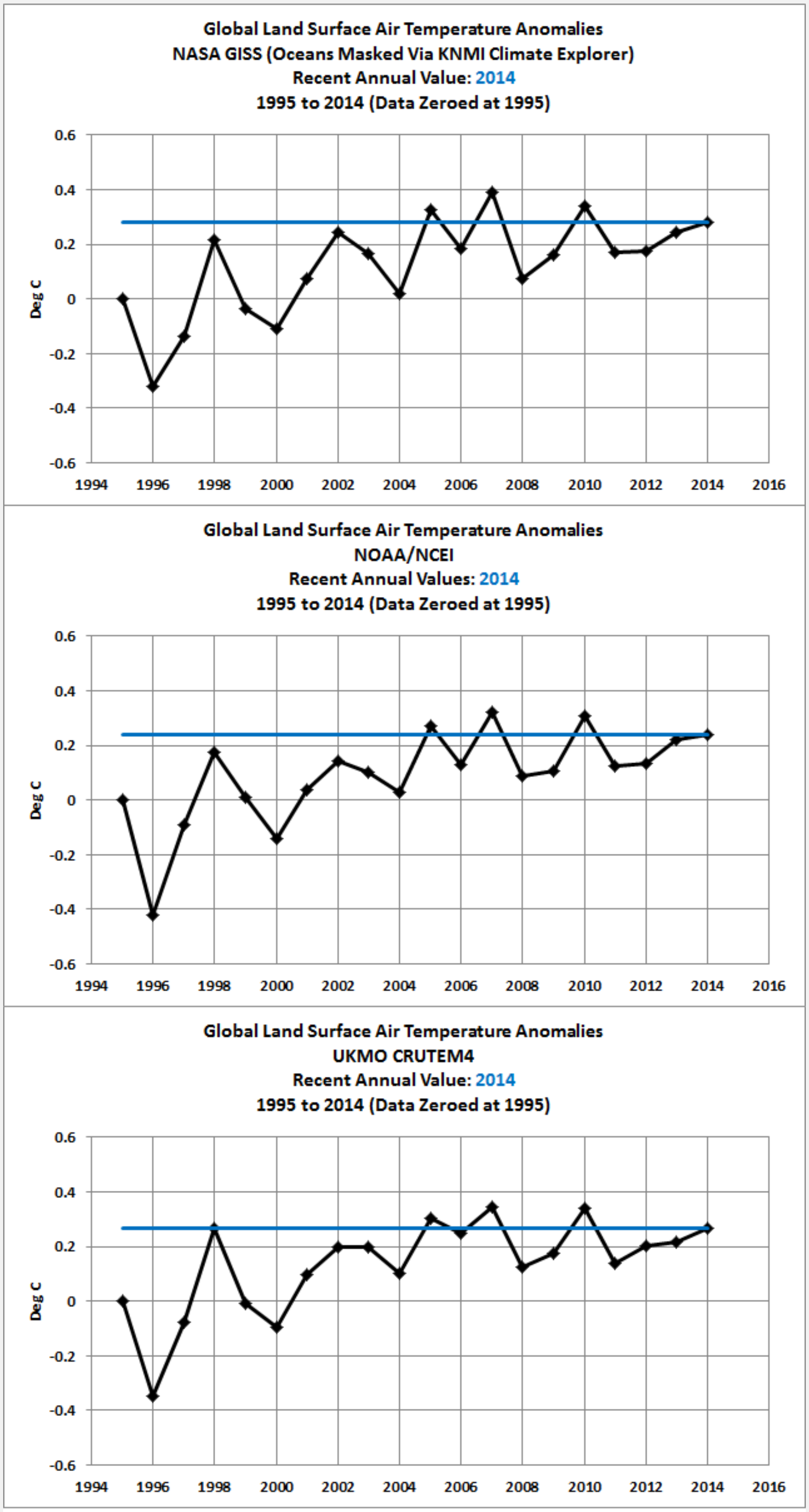

Global Land Surface Air Temperature Anomalies
NASA GISS (Oceans Masked Via KNMI Climate Explorer)
Recent Annual Value: 2014
1995 to 2014 (Data Zeroed at 1995)
Deg C
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
Global Land Surface Air Temperature Anomalies
NOAA/NCEI
Recent Annual Values: 2014
1995 to 2014 (Data Zeroed at 1995)
Deg C
Global Land Surface Air Temperature Anomalies
UKMO CRUTEM4
Recent Annual Value: 2014
1995 to 2014 (Data Zeroed at 1995)
Deg C

Figure GD-2-2

BUT GLOBAL SEA SURFACE TEMPERATURES IN 2014 WERE AT RECORD HIGHS FOR THE INSTRUMENT TEMPERATURE RECORD

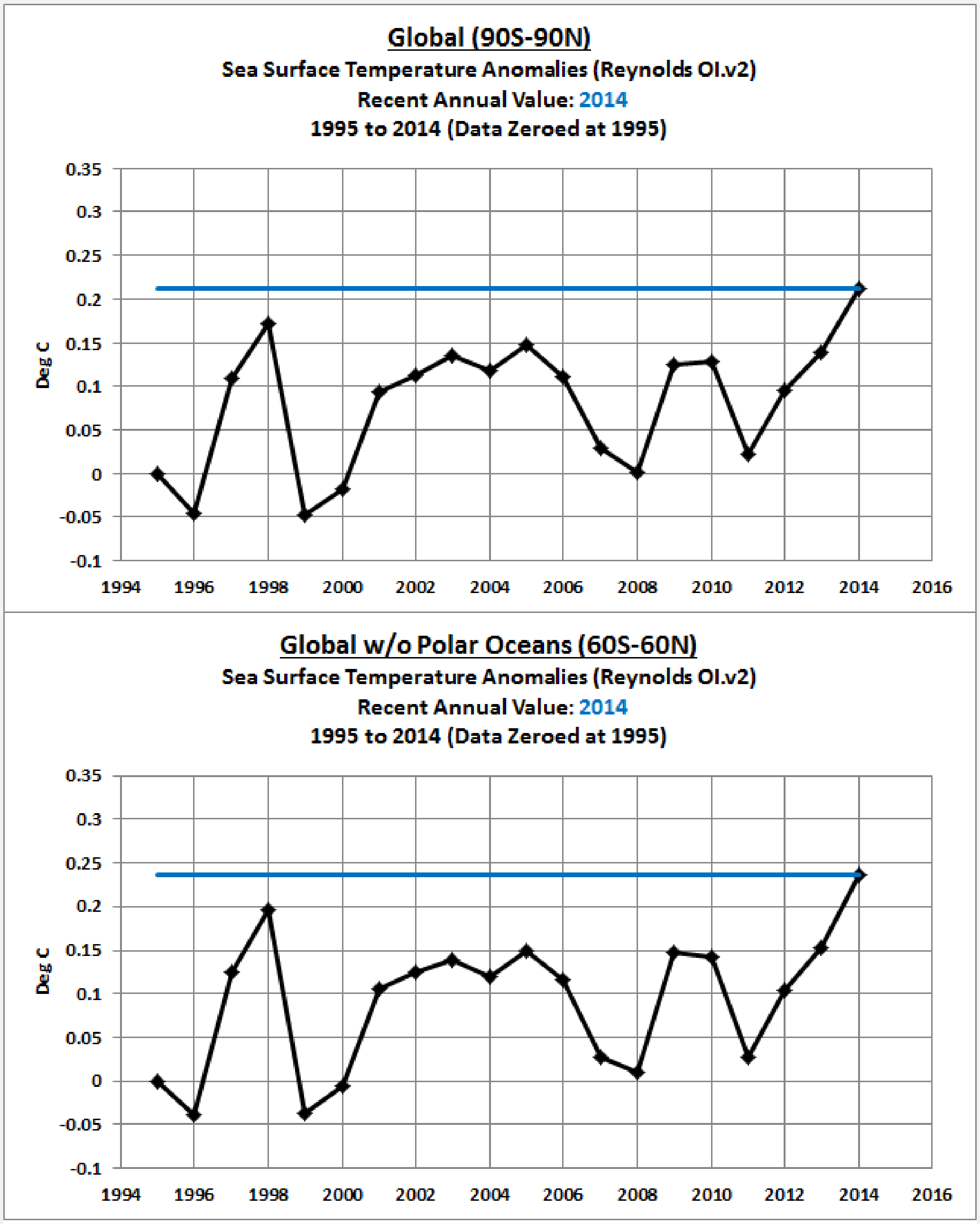


Figure GD-2-3

Logically, if global land air plus ocean surface temperatures were at (or near) record highs in 2014 (top graph in Figure GD-2-1), and if the air over the continental land masses was not at record highs (Figure GD-2-2), then the ocean surfaces had to be responsible for the record warm global surfaces. See Figure GD-2-3.

I've presented the sea surface temperature data two ways in Figure GD-2-3, with and without the polar oceans. The suppliers of global land+ocean surface temperature data (GISS, NCEI, and UKMO) treat the polar oceans differently, so I've shown the data two ways. (We'll discuss those differences between the data suppliers in more detail in part 2 of this book.) Because the surface area of the Southern Ocean surrounding Antarctica (about 22 million km^2) is greater than that of the Arctic Ocean (about 16 million km^2), the cooling taking place on the surface of the Southern Ocean outweighs the warming taking place on the surface of the Arctic Ocean. That's why the data with the polar oceans shows slightly less warming in Figure GD-2-3 than the data that excludes them. That, of course, was another reason I presented global sea surface temperature data with and without the polar oceans…to show you that basic reality.

INFO ABOUT THE SEA SURFACE TEMPERATURE DATASET AND CLIMATE MODEL OUTPUTS

I'm using NOAA's Optimum Interpolation Sea Surface Temperature data (a.k.a. Reynolds OI.v2) for this discussion, because:

- It is the longest running satellite-enhanced sea surface temperature dataset available,
- It's satellite data are bias adjusted based on temperature measurements from ship inlets and from buoys (both moored and drifting), and
- Most importantly, NOAA's Reynolds OI.v2 data have been called "a good estimate of the truth". See Smith and Reynolds (2004) Improved Extended Reconstruction of SST (1854-1997). The authors stated about the Reynolds OI.v2 data (my boldface):

  > *Although the NOAA OI analysis contains some noise due to its use of different data types and bias corrections for satellite data, **it is dominated by satellite data and gives a good estimate of the truth**.*

Additional notes about my choice of sea surface temperature datasets:

- Though satellite data are not included in the new NOAA ERSST.v4 data, Reynolds OI.v2 data are used for quality control of the new ERSST.v4 dataset. See the post Quick Look at the DATA for the New NOAA Sea Surface Temperature Dataset.
- Along with HADISST data, Reynolds had been used (past tense) in the GISS Land-Ocean Temperature Index data until early in 2013, but GISS switched to NOAA's ERSST.v3b data, apparently to bring their long-term trends into line with the NCDC and HADCRUT datasets. During the satellite era, the change from Reynolds OI.v2 to ERSST.v3b data had little impact. See the post A Look at the New (and Improved?) GISS Land-Ocean Temperature Index Data. Reynolds

OI.v2 data (along with HADISST) are still available for presentations at the GISS Map-Making Webpage and for download by researchers.

- Reynolds OI.v2 data are also used in a number of reanalyses, including CMCC C-GLORS, ECMWF ORAS4, ECMWF ORAS3, GFDL, GLORYS2V1, GMAO and NCEP/GODAS. See the Reanalysis.org webpage Overview of current ocean reanalyses.

The Reynolds OI.v2 sea surface temperature data presented in this discussion are from the KNMI Climate Explorer…as are the model simulations of sea surface temperatures.

The climate models presented in this post are those stored in the CMIP5 archive, which was used by the IPCC for their 5th Assessment Report (AR5). The CMIP5 climate model outputs of sea surface temperature are available through the KNMI Climate Explorer, specifically through their Monthly CMIP5 scenario runs webpage, under the heading of Ocean, ice and upper air variables. Sea surface temperature is identified as "TOS" (temperature ocean surface). I've used the simulations with the historic and RCP8.5 forcings.

Back to the discussion of global sea surface temperatures:

BUT LOOKING AT THE GLOBAL DATA DOES NOT TELL US WHICH OCEAN BASIN WAS WARMEST…OR WHY

The surfaces of the oceans do not warm (or cool) uniformly. There are naturally occurring, coupled ocean-air processes that dictate the surface temperatures of the individual ocean basins, so looking at global data and claiming they're at record highs can be, and often is, misleading. Why? Because looking at the data globally doesn't tell us where the warming occurred or if it occurred naturally. Claims of record-high global ocean surface temperatures, without disclosing the cause, implies the new record was caused by greenhouse gases.

Let's take a look at the sea surface temperature anomalies since 1995 to see which ocean basin or basins were at record-high levels in 2014.

That is, we're still trying to determine the cause or causes of the claims of record high global surface temperatures for 2014.

We'll start with the North and South Atlantic. See the two time-series graphs in Figure GD-2-4. Sea surface temperatures were not close to being at record highs in the North Atlantic, and were not at record levels in the South Atlantic.

Also keep in mind, when looking at the following graphs, that the temperature anomalies are not uniform for a given basin. That is, some parts of a specific ocean basin may be warmer than normal, while others may be cooler, but, all in all, the surface temperatures for most ocean basins were not at record high levels as you'll see.

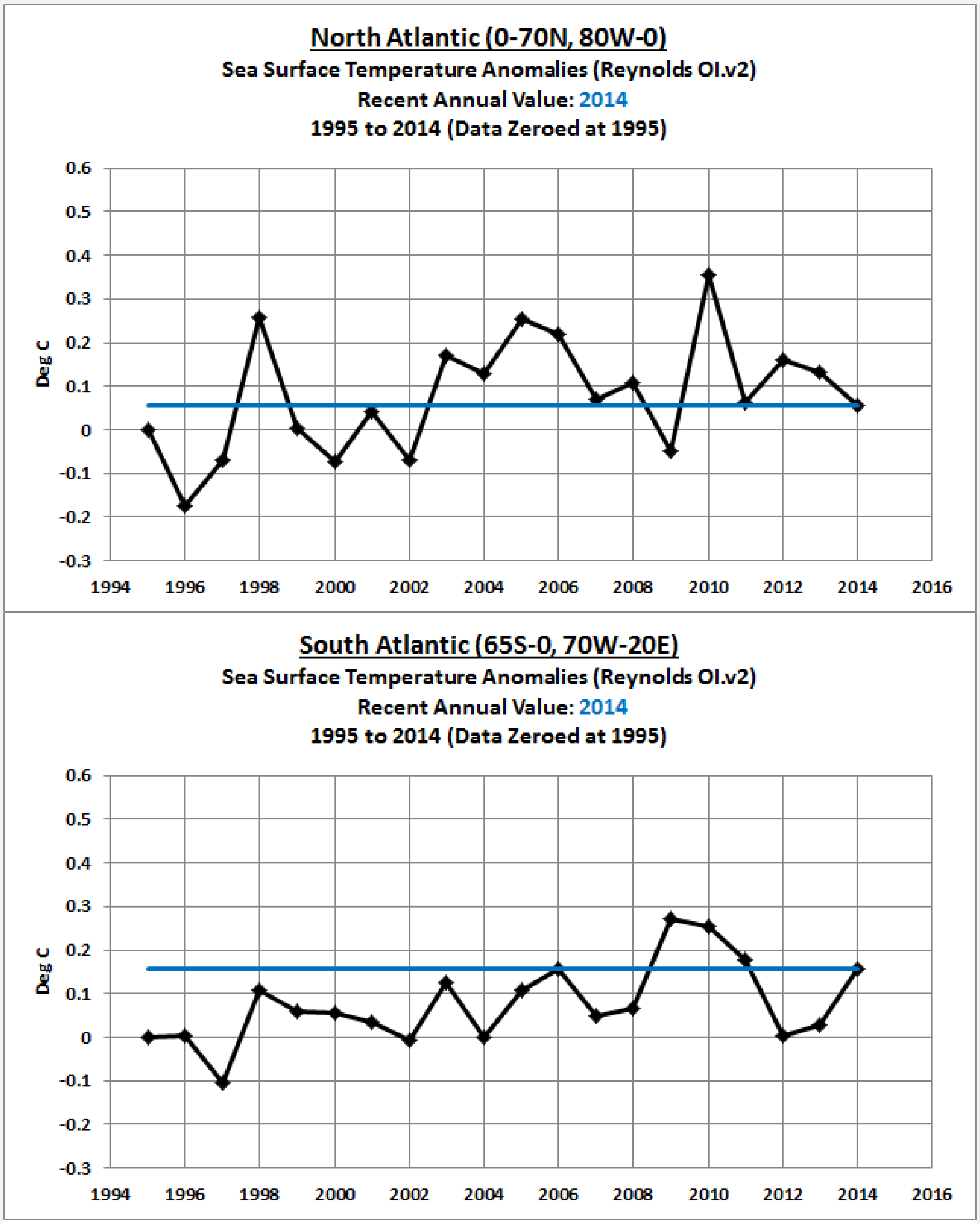


Figure GD-2-4

Let's look at the polar oceans next, Figure GD-2-5. Sea surface temperatures in the Arctic Ocean were close to, but not quite at, record highs. At the other end of the globe, the Southern Ocean surrounding Antartica shows cooling over the past 20 years. In fact, the data show the surface of the Southern Ocean was at or near record **cool** levels…well at least since 1995.

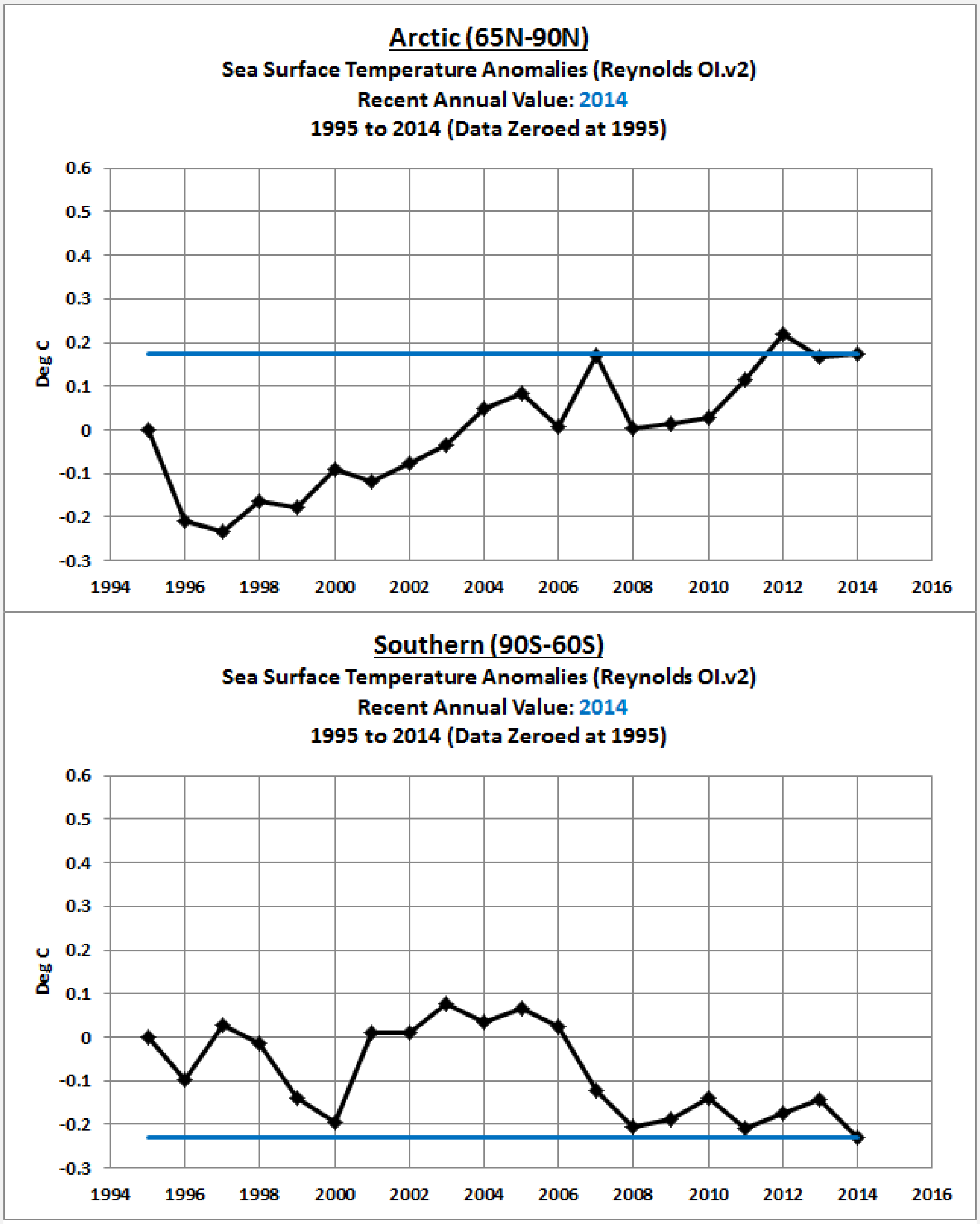


Figure GD-2-5

Next are the Indian and South Pacific basins. As shown in Figure GD-2-6, neither basin showed record warm surfaces as a whole in 2014.

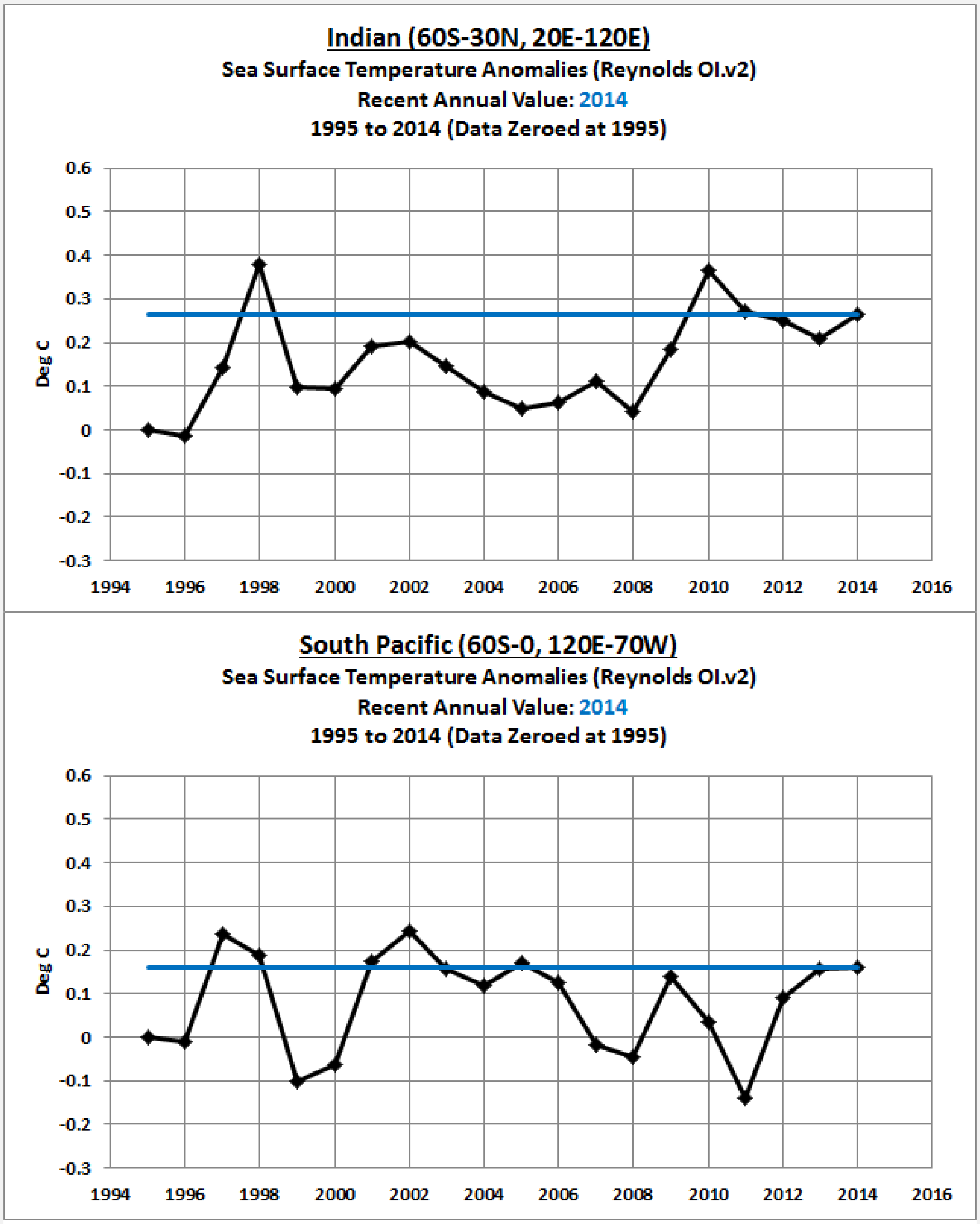


Figure GD-2-6

THAT LEAVES THE NORTH PACIFIC AS THE CAUSE OF THE REPORTED RECORD-HIGH GLOBAL SEA SURFACE TEMPERATURES AND GLOBAL LAND+OCEAN SURFACE TEMPERATURES IN 2014

Land surface air temperatures were not at record highs in 2014 (Figure GD-2-2), and none of the ocean basins we've looked at so far were at record highs in 2014 (Figures GD-2-4 through GD-2-6). That means the North Pacific had to be the cause of the reports of record-high sea surface and record-high land+ocean surface temperatures. Figure GD-2-7 confirms that.

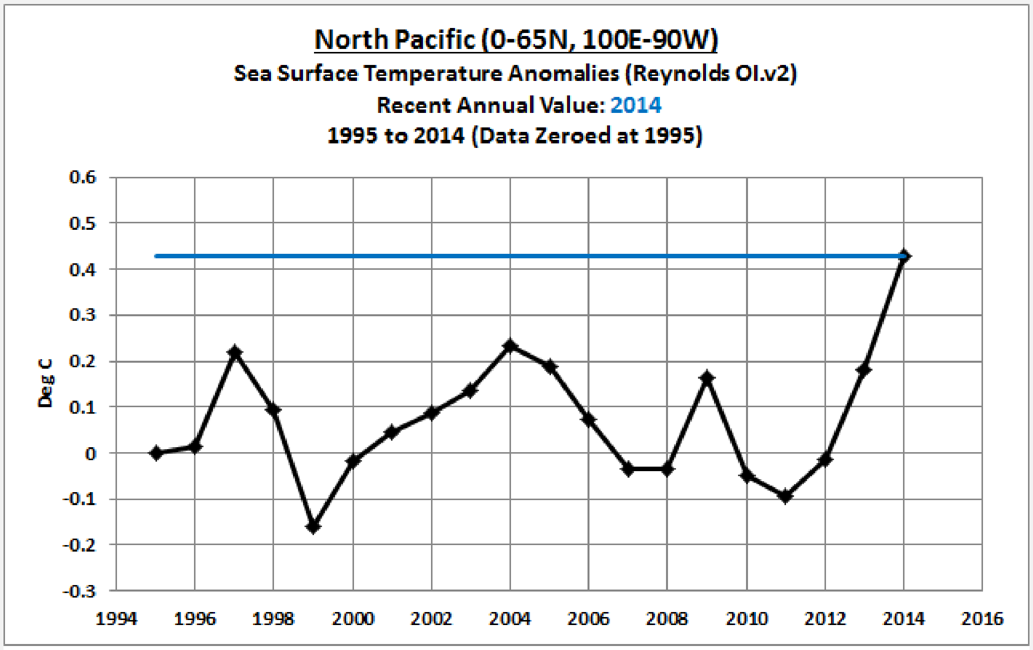


Figure GD-2-7

That's hard to miss, yet few if any reports by the mainstream media mentioned that the record highs were limited to one ocean basin. Let's carry our examination one step farther. We'll divide the sea surface temperature data for the North Pacific in two parts, split at the dateline. For the next two graphs, I've doubled the scaling of the y-axis (vertical axis) from the range used for Figures GD-2-4 to GD-2-7.

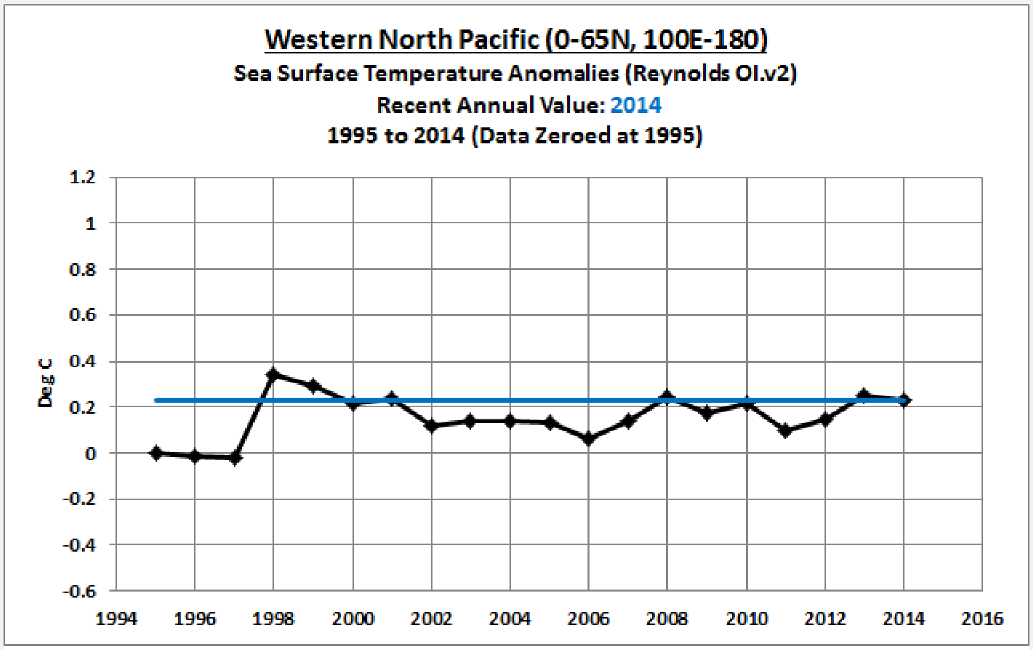


Figure GD-2-8

The Western North Pacific (Figure GD-2-8) doesn't show anything unusual in 2014. In fact, the surface temperatures there have been remarkably stable since their (upward shift) response to the 1997/98 El Niño. The same cannot be said for the Eastern North Pacific, as shown in Figure GD-2-9.

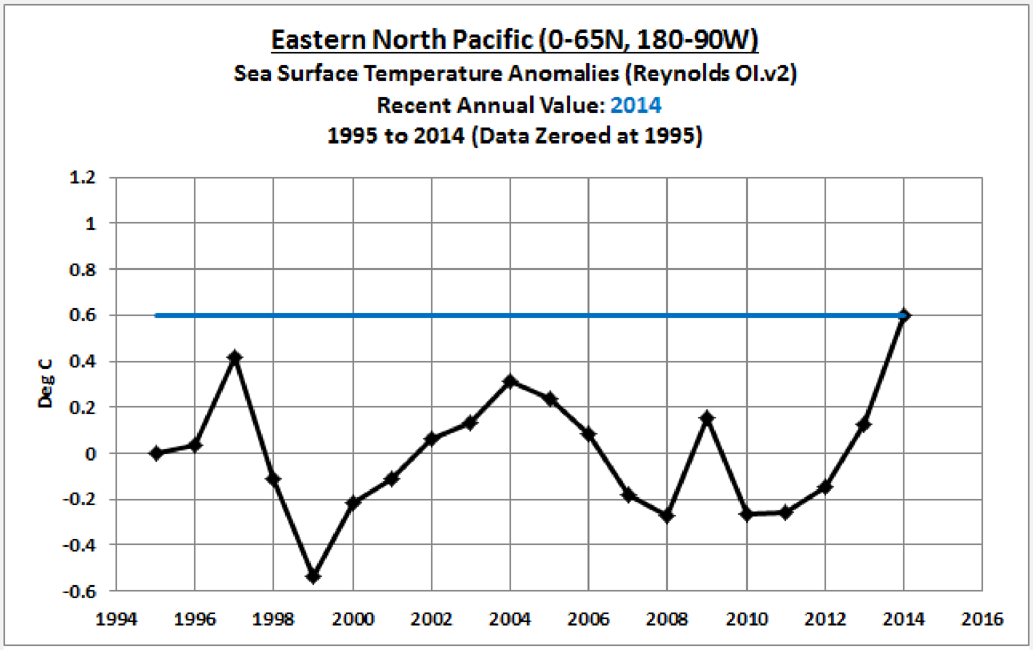


Figure GD-2-9

The primary reason for the record-high sea surface temperatures in the Eastern North Pacific (and in turn the reported record-high land+ocean surface temperatures globally) is plainly visible in the map of global sea surface temperature anomalies in Figure GD-2-10. I've highlighted the Eastern North Pacific bordered by the coordinates of 0-65N, 180-90W. It captures a portion of the Gulf of Mexico and a small part of Hudson Bay, but those additional portions have little influence on this discussion. Using those coordinates also misses a small part of the extreme eastern tropical Pacific, but it's too small to be of concern.

Note the area of unusual high sea surface temperature anomalies west of Canada and the U.S. That persistent pocket of warmer-than-normal surface temperatures was nicknamed "The Blob" by researchers in 2013, when it first appeared. More on the natural cause of The Blob in a few moments.

We'll also discuss the naturally caused pocket of warmer-than-normal water off the Baja Peninsula of Mexico, which also contributed to the extraordinary jump in the surface temperatures of the Eastern North Pacific.

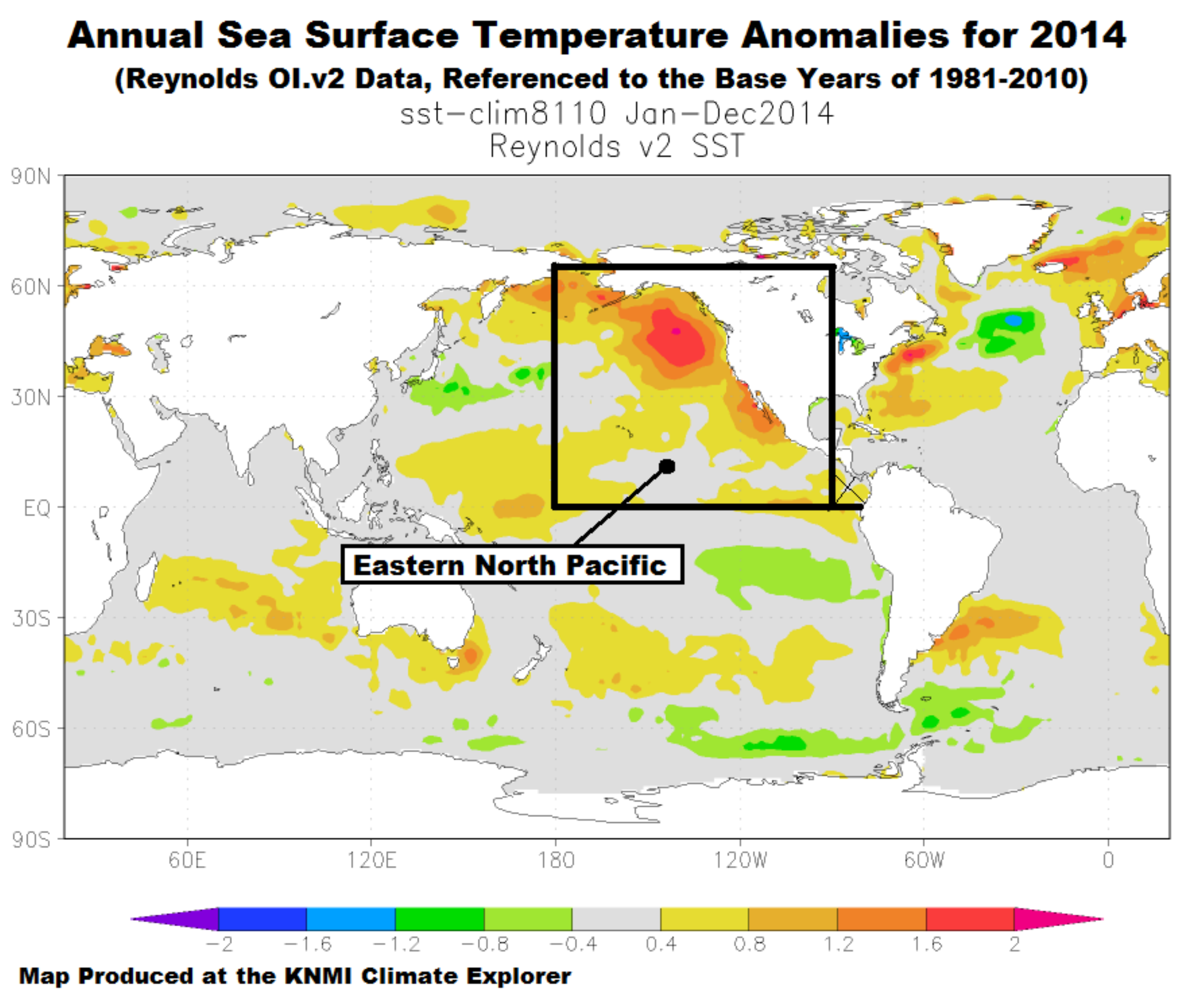


Figure GD-2-10

THE SURFACES OF THE PACIFIC, NORTH PACIFIC AND EASTERN NORTH PACIFIC SHOWED NO WARMING FROM 1995 TO 2013, 19 YEARS

Alarmists have the easiest jobs in the climate science debate. They constantly make claims that aren't supported by data or by climate models. Even though extreme weather existed long before the industrial revolution, alarmists will cry global warming and climate change (assumedly the man-made varieties) with every hurricane, tornado, flood, drought, heatwave, cold spell, blizzard, etc. They made the expected claims about the record highs in 2014: "Just what AGW predicts." But reality as we know is often far different.

Based on the linear trend, the surface of the North Pacific showed no warming for 19 years. See the top graph in Figure GD-2-11. Over that same period of 1995 to 2013, the Eastern North Pacific showed a slight cooling, as shown in the bottom graph.

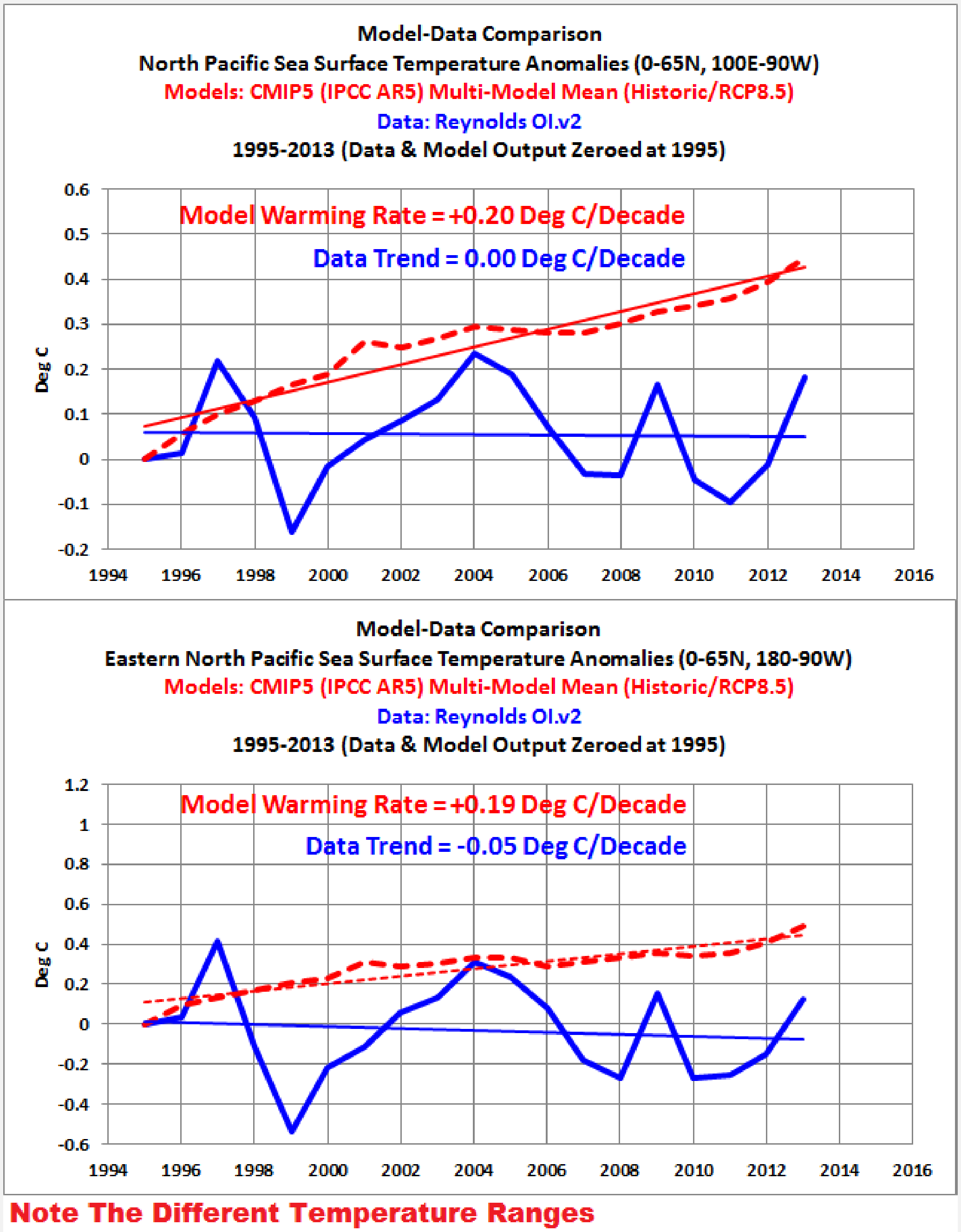


Figure GD-2-11

Climate models, on the other hand, show that the North Pacific and Eastern North Pacific should have warmed more than 0.3 deg C (0.54 deg F) over those 19 years.

You'll note I've used different scales of the vertical axis (y-axis) in the above two graphs.

The Pacific Ocean as a whole…the largest body of water on this planet…showed no warming for that 1995-2013 timeframe, as shown in Figure GD-2-12, and, once again, the models showed they should have warmed more than 0.3 deg C (0.54 deg F) if they were warmed by man-made greenhouse gases.

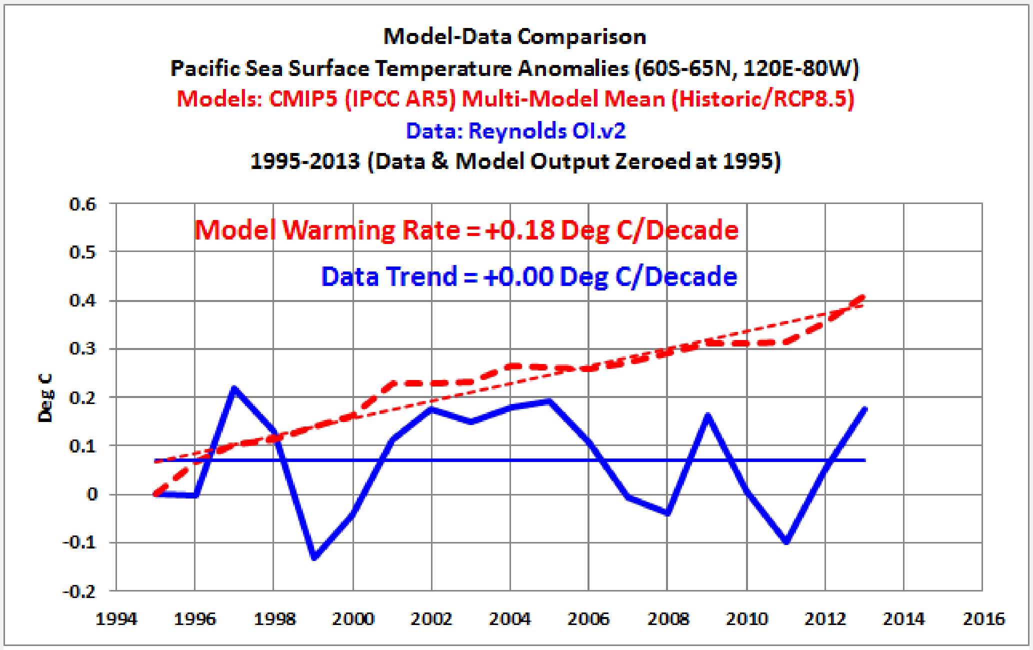


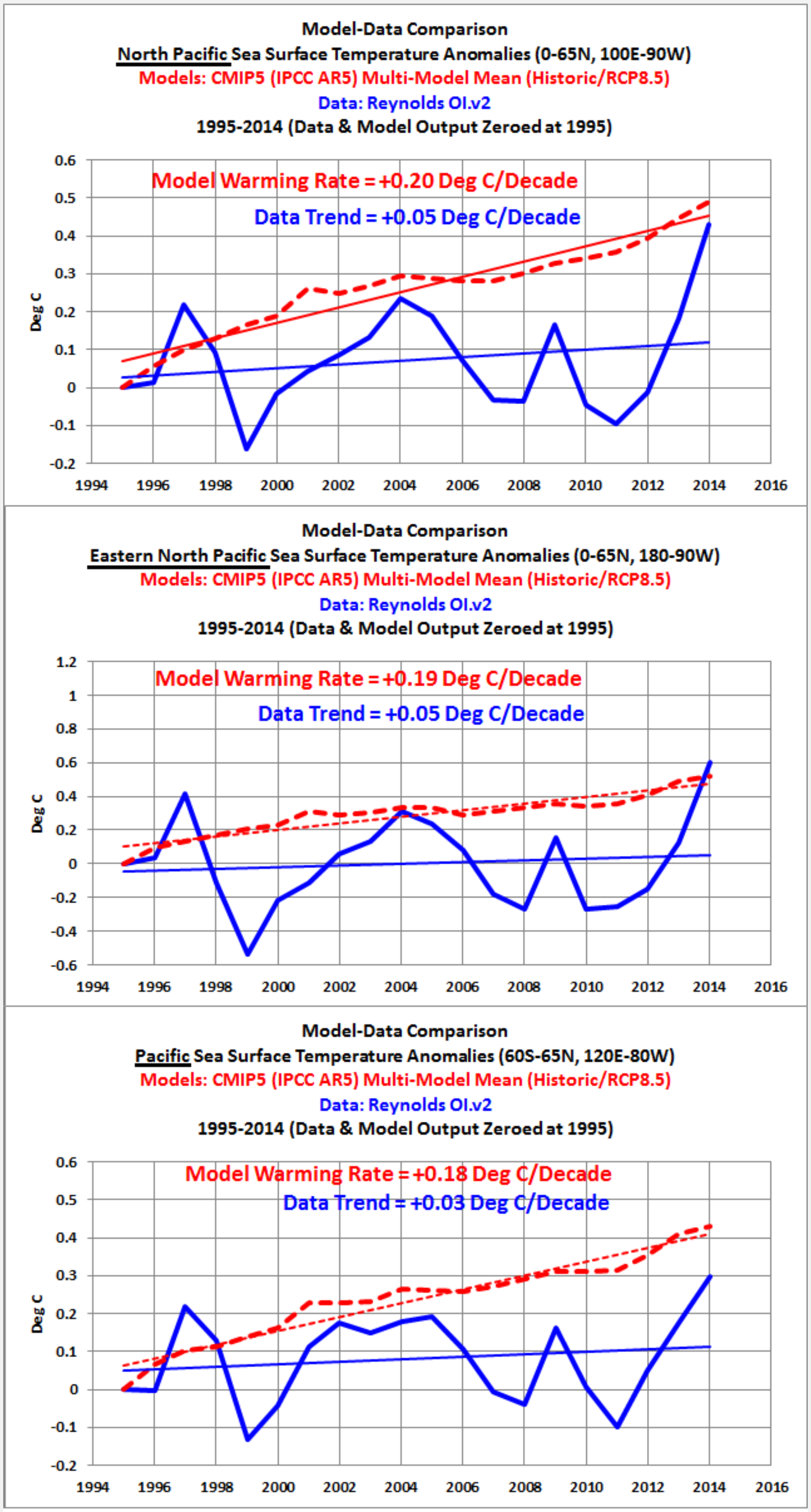
Figure GD-2-12

THE LARGE NATURALLY CAUSED SPIKE IN THE SEA SURFACE TEMPERATURES OF THE NORTH PACIFIC DID NOT MAGICALLY ELIMINATE THE MODEL-DATA DIFFERENCES

The unusual hotspot in the eastern extratropical North Pacific stands out like a sore thumb in the map we showed earlier in Figure GD-2-10. It also had strong impacts on the sea surface temperature data of the North Pacific (Figure GD-2-7 above) and the Eastern North Pacific (Figure GD-2-9 above).

But that spike did not overcome the underlying problem with the models, which is that they simulate way too much warming in the North Pacific, the Eastern North Pacific and for the Pacific Ocean as a whole. Recall from the Introduction that the Pacific Ocean covers more of the surface of the planet than all of the continental land masses combined. That helps to put these model failings into perspective.

So let's update the last three graphs with the 2014 data.   Instead of showing no warming since 1955 or a slight cooling, the surfaces of the North Pacific, the Eastern North Pacific and in the Pacific Ocean as a whole all now show a slight warming for the 20-year period of 1995 to 2014. But that slight warming does not come anywhere close to eliminating the model-data difference. See Figure GD-2-13.



Note The Different Temperature Ranges

Figure GD-2-13

While there are model-data differences in other ocean basins, the tremendous model failings in the simulations of the Pacific sea surface temperatures is one of the primary reasons why models do such a bad job of simulating global surface temperatures.

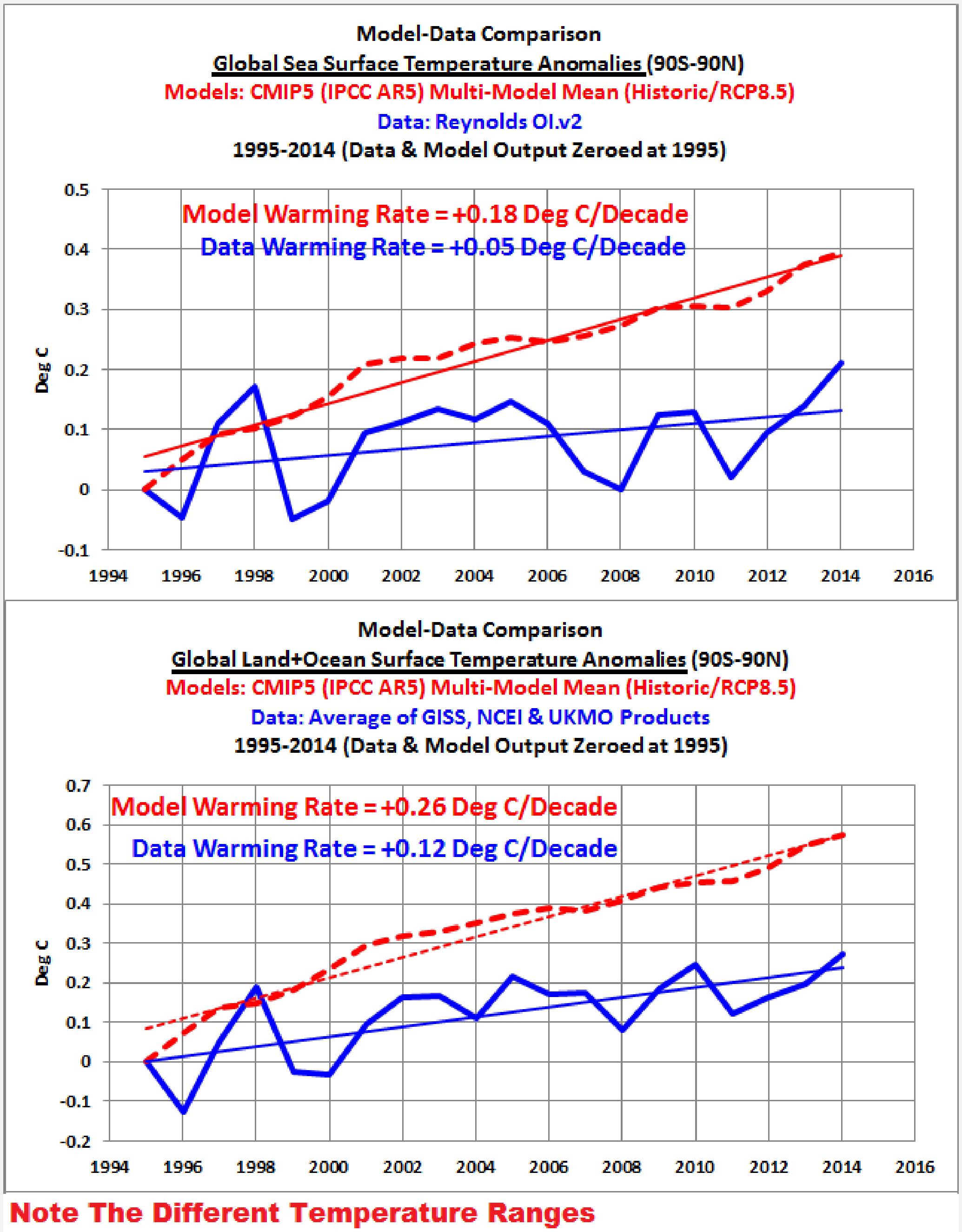


Figure GD-2-14

The top graph in Figure GD-2-14 compares modeled and observed global sea surface temperature anomalies for the 20-year period of 1995-2014. The models more than triple the observed warming of the surfaces of the global oceans during this 2-decade period.

The bottom graph compares model simulations of global land+ocean surface temperature anomalies for the same period to the average of the NASA GISS, NOAA NCEI and UKMO products. Keep in mind the GISS and NCEI data include the overcooked "pause-buster" sea surface temperature data from NOAA. Even with that "pause-buster" data, the observed global land+sea surface temperatures show a trend that's half the warming rate of the climate model simulations.

THE CAUSE OF THE BLOB

I first reported on the unusual hotspot in the eastern extratropical North Pacific in the August 2013 blog post here. Almost a year later, Nick Bond, a Research Meteorologist from the Joint Institute for the Study of the Atmosphere and Ocean (JISAO) and also the State Climatologist for the State of Washington, nicknamed that persistent hotspot "The Blob". See his June 2014 message *The Blob: Warm Water off the Coast of the PNW and What it May Mean for Our Summer Weather,* which is found in the May Event Summary from the Office of the State of Washington Climatologist. Nick Bond and others went on to publish a paper about The Blob and its effects.

Bond et al. (2015) Causes and Impacts of the 2014 Warm Anomaly in the NE Pacific was published in April 2015. Its abstract reads (my boldface):

> *Strongly positive temperature anomalies developed in the NE Pacific Ocean during the boreal winter of 2013–2014. Based on a mixed layer temperature budget, **these anomalies were caused by lower than normal rates of the loss of heat from the ocean to the atmosphere and of relatively weak cold advection in the upper ocean. Both of these mechanisms can be attributed to an unusually strong and persistent weather pattern featuring much higher than normal sea level pressure over the waters of interest.** This anomaly was the greatest observed in this region since at least the 1980s. The region of warm sea surface temperature anomalies subsequently expanded and reached coastal waters in spring and summer 2014. Impacts on fisheries and regional weather are discussed. It is found that sea surface temperature anomalies in this region affect air temperatures downwind in Washington state.*

A University of Washington press release for the paper translates that into layperson language. The press release 'Warm blob' in Pacific Ocean linked to weird weather across the U.S. includes:

> *The new study explores the blob's origins. It finds that it relates to a persistent high-pressure ridge that caused a calmer ocean during the past two winters, so less heat was lost to cold air above. The warmer temperatures we see now aren't due to more heating, but less winter cooling.*

That's an interesting realization. The unusually warm surface and subsurface temperatures associated with The Blob weren't due to more heating; they were due to less winter cooling caused by the ridge of high pressure. As Bond et al. state in the Introduction of their paper (where SLP is sea level pressure):

> …the unusually high SLP in the region of interest impacted the wind-forced currents and wind-generated mixing, as well as the surface heat loss due to the combination of evaporation, conduction, and net shortwave (solar) and infrared radiation.

The Blob is not solely a surface phenomenon; it has also caused above-normal temperatures to depths of that spot in the eastern extratropical North Pacific. As the University of Washington press release states:

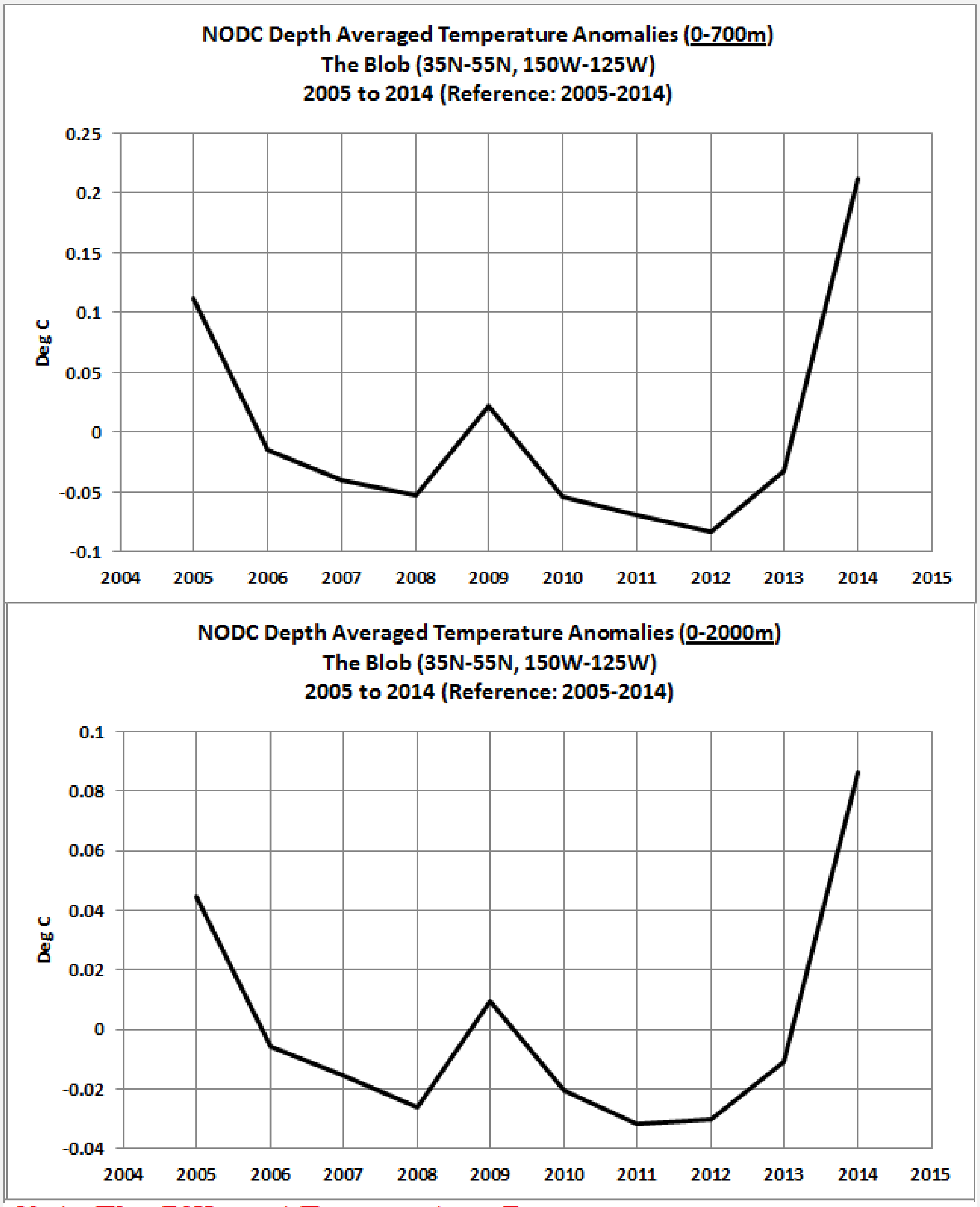
> *Bond coined the term "the blob" last June in his monthly newsletter as Washington's state climatologist. He said the huge patch of water – 1,000 miles in each direction and* ***300 feet deep*** *– had contributed to Washington's mild 2014 winter and might signal a warmer summer.*

I presented the next two illustrations in my March 2015 blog post North Pacific Update: The Blob's Strengthening Suggests It's Not Ready to Depart.

While The Blob had not had a noticeable impact on the subsurface temperatures to 700 meters and to 2000 meters in 2014 for the entire North Pacific (see the graph here), The Blob did have a noticeable impact on the subsurface temperatures to those depths in its specific location. I used the coordinates of 35N-55N, 150W-125W for the two graphs in Figure GD-2-15.

To accommodate the differences in the ocean heat uptake, I've used different scales for the two graphs in Figure GD-2-15.

Note how the upticks were greater in 2014 than in 2013. That is, although The Blob formed in 2013, it had a greater impact on the subsurface temperatures in that location in 2014.



Note The Different Temperature Ranges

Figure GD-2-15

The following is the discussion from that March 2015 post about The Blob (I've updated the Figure number.)

HOW DEEP DOES THE BLOB GO?

Figure GD-2-16 is a cross section of the subsurface temperature anomalies of the Eastern Pacific Ocean available from the ECMWF webpage here. It presents the output of their ORAS4 reanalysis. Keep in mind, a reanalysis is the output of a computer model that uses data as inputs. But with all of the ARGO floats bobbing around in the oceans, and assuming the ARGO data are used in this reanalysis, this should be a reasonable representation.

Cross Section of Pacific Ocean Temperature Anomalies to Depth for the Longitudes 160W-90W (Source: ECMWF ORAS4)

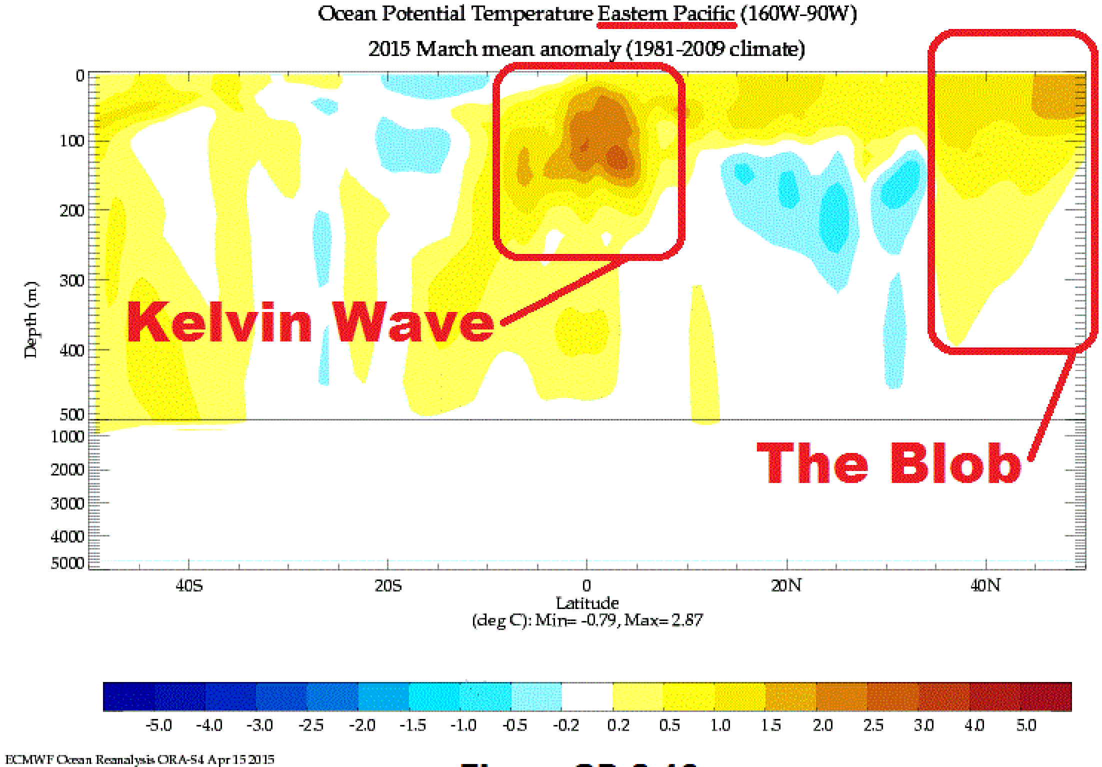


Figure GD-2-16

The cross section is for the month of March 2015. In the top portion, it presents the average subsurface temperature anomalies to depths of 500 meters. The x-axis (horizontal axis) stretches from 50S on the left to 50N on the right. The longitudes are 160W-90W. Basically, if we were to take a slice of the Pacific Ocean that was bordered by the coordinates of 50S-50N, 160W-90W and look from east to west, those are the average temperature anomalies at depth. The Blob is visible to the right, and appears as the elevated subsurface temperature anomalies. So The Blob is not simply a surface phenomenon. But we would expect that with wind-driven ocean mixing.

I've also highlighted the most recent Kelvin wave, which is making its way from west to east along the equator. Much of that pocket of warm water will rise to the surface over the upcoming months and likely strengthen the current El Niño.

The Blob is associated with a ridge of high pressure, according to Bond et al., but an animation of the sea surface temperature anomalies of the North Pacific indicate the pocket of warmer-than-normal waters originated in the Western North Pacific. I created that animation for that March 2015 blog post North Pacific Update: The Blob's Strengthening Suggests It's Not Ready to Depart.

The animation is here.

About the animation, I wrote:

> I've provided Animation 1 to confirm that the elevated sea surface temperatures originally formed, as one would expect, in the west-central North Pacific during the back-to-back La Niñas of 2010/11 and 2011/12. What came next was unexpected. Those elevated sea surface temperatures then migrated eastward to create The Blob.
>
> Animations of maps of monthly sea surface temperature anomalies can be quite volatile, with weather effects and seasonal components creating a lot of visual noise. To minimize the monthly volatility, each of the following maps presents the average sea surface temperature anomalies for a full year. The annual maps then advance on a monthly basis. That is, the first map covers the 12-month period of January 2010 to December 2010. The second map is for February 2010 to January 2011. The third map: March 2010 to February 2011. And so on through the last map for April 2014 to March 2015. This is similar to smoothing time-series data with a 12-month running-mean filter.
>
> You'll also note the evolution of the 2014/15 El Niño later in the animation. It appears to enhance The Blob and cause the sea surface temperatures to rise along the west coast of North America.

So, while The Blob is associated with a ridge of high pressure in the eastern North Pacific, the pocket of warm water originated in the western North Pacific. One might assume that the ridge of high pressure then prevented the normal cooling of that warm water during the boreal winter of 2013/14…and once again in 2014/15. Or maybe the ridge of high pressure also tracked across the North Pacific, accompanying the pocket of warm water, though I haven't seen that discussed in any paper.

THE IMPACTS OF THE RIDGE OF HIGH PRESSURE ON NORTH AMERICAN WEATHER

The Blob is coupled with a ridge of high pressure in the same general location, according to Bond et al. (2015).

The persistent ridge of high pressure has been linked with the multiyear drought and elevated surface temperatures in the western United States. Like The Blob, that ridge of high pressure has also been given a nickname: The Ridiculously Resilient Ridge.

Rain that normally makes its way to California has been diverted northward into British Columbia by the Ridiculously Resilient Ridge

The September 2014 *Special Supplement to the Bulletin of the American Meteorological Society* – Explaining Extreme Events of 2013 from a Climate Perspective includes 3 papers about the California drought.

First paper: Swain et al. (2014) *The Extraordinary California Drought of 2013/14: Character, Context, and the Role of Climate Change*. Their conclusion begins:

> *The 2013/14 California drought was an exceptional climate event. A highly persistent large-scale meteorological pattern over the northeastern Pacific led to observationally unprecedented geopotential height and precipitation anomalies over a broad region. The very strong ridging and highly amplified meridional flow near the West Coast of North America in 2013/14 was structurally similar to—but spatially and temporally more extensive than—atmospheric configurations that have been previously linked to extreme dryness in California (Mitchell and Blier 1997; Namias 1978a,b).*

Not too surprisingly, Swain et al. then went on the blame man-made global warming for the drought. Quite absurdly, to come to that conclusion, they used the climate models stored in the CMIP5 archive…which bear no relationship to climate on Earth as it existed in the past, presently exists, or might exist in the future.

Second paper: Wang and Schubert (2014) *Causes of the Extreme Dry Conditions over California during Early 2013*. They start their conclusion:

> *The extreme precipitation deficits over California during early 2013 resulted from considerably fewer North Pacific storms reaching California, due to the blocking by persistent high anomalies over the northeast Pacific.*

Wang and Schubert also use models for attribution, but they use AMIP models. As discussed in Chapter 2.2, AMIP models use observations, such as actual sea surface temperature data and sea ice data, as inputs. Based on their AMIP models, Wang and Schubert come to a somewhat different conclusion than Swain et al. (My boldface.):

> *Our model results show that the concurrent SST anomalies do force a predilection for dry events over California though considerably weaker than observed, suggesting that atmospheric internal variability accounts for the extreme magnitude of this climate event. An assessment of the role of the long-term warming trend shows that it forces a high anomaly over the northeast Pacific resulting in less North Pacific storms reaching California. The warming trend, however, also leads to increased atmospheric humidity over the northeast*

> *Pacific, thus, facilitating wetter events over California.* ***The above two effects appear to counteract each other, contributing to no appreciable long-term change in the risk for dry climate extremes over California since the late 19th century.***

Third paper: Funk et al. (2014) *Examining the Contribution of the Observed Global Warming Trend to the California Droughts of 2012/13 and 2013/14*. Their conclusion begins (My boldface):

> *While the SST trend mode has resulted in large SST increases (Fig. 4.2b) that appear associated with an equatorial precipitation dipole response contrasting increases over the western Pacific and decreases over the central Pacific (Fig. 4.2c,d), the location of most of this warming is to the west of the key sensitivity areas identified in our CMIP5 composite (Fig. 4.1a). While this trend pattern does resemble SST variations associated with drying in the western United States (Gershunov and Cayan 2003), removing this warming did not increase the CAM5 precipitation over California in a statistically significant manner; thus, our results do not indicate that this long-term warming trend contributed substantially to the 2013 and 2014 drought events.* ***This result appears consistent with the lack of a long-term downward trend in California precipitation (Fig. 4.1b).***

Because Funk et al. (2014) use climate models stored in the CMIP5 archive for their attribution, we can disregard their results as well.

However, let's take a look at their Figure 4.1b, because they called our attention to it with their statement that there is a "**lack of a long-term downward trend in California precipitation"**. It's a model-data comparison of California precipitation. I've included it as my Figure GD-2-17.

As shown, the data (black curve) show multidecadal variations in California precipitation from the early 1900s to the early 2000s, while the models stored in the CMIP5 archive (blue curve) show there should have been a gradual increase in precipitation there. However, after adjusting the model results for modeled El Niño and La Niña events (ENSO), which the models do not simulate properly, the California precipitation should have decreased (red curve). Any way you slice it, the models do a horrendous job of simulation the observed California Precipitation.

Figure 4.1b from Funk et al. (2014)

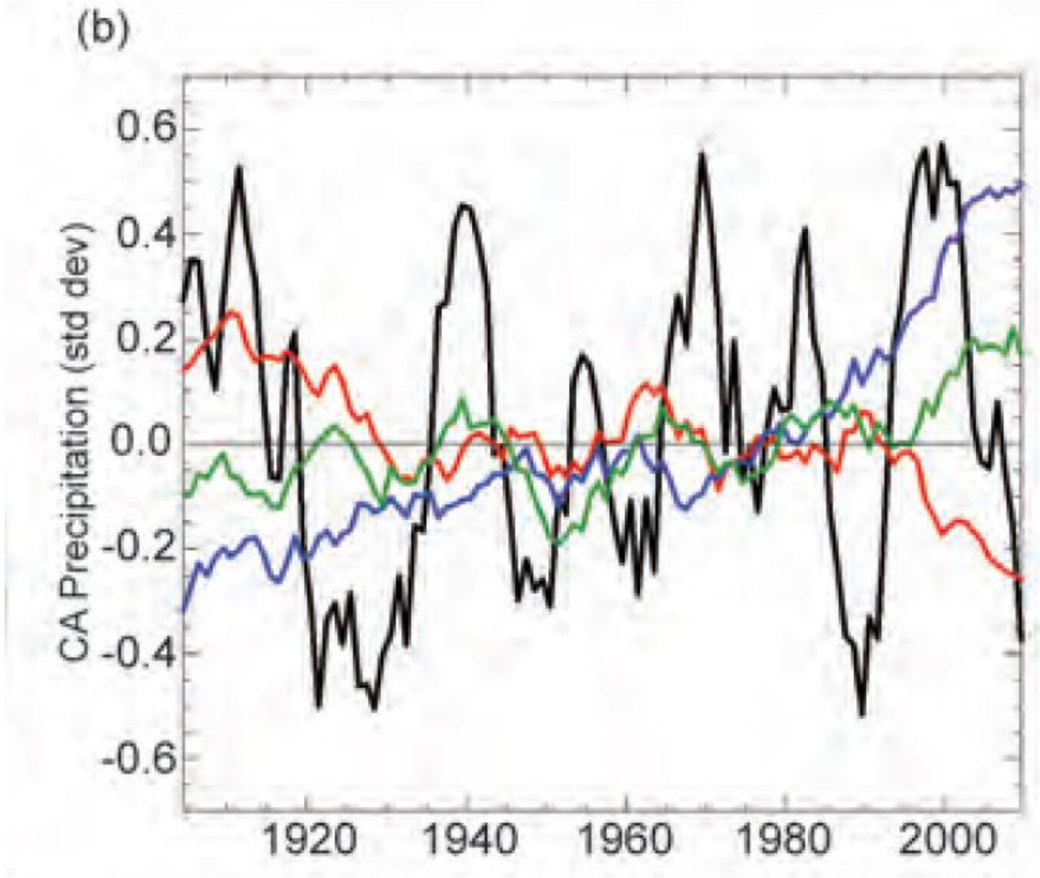


Fig. 4.1. ... (b) Ten-year averages of standardized California precipitation based on observations (black), ensemble mean ENSO CMIP5 precipitation (blue), and ENSO-residual CMIP5 precipitation (red). Also shown is a time series of the intermodel standard deviations (green).

Figure GD-2-17

The Funk et al. (2014) conclusions continue with a lot of speculation based on the CMIP5-archived models. But we've already shown in Figures GD-2-11 through GD-2-14 that climate models do not properly simulate the sea surface temperatures globally, or for the Pacific, or the North Pacific, or the Eastern North Pacific. So we can disregard their conjecture.

In addition to the drought and warmer-than-normal temperatures in the western U.S. states, that ridiculously resilient ridge has also been blamed the colder-than-normal surface temperatures in the eastern United States over the past couple of winters. The paper that confirms this is Hartmann (2015) Pacific sea surface temperature and the winter of 2014 (paywalled). The preprint copy is here. The abstract reads (My Boldface.):

> *It is shown from historical data and from modeling experiments that a proximate cause of the cold winter in North America in 2013–2014 was the pattern of sea surface temperature (SST) in the Pacific Ocean. Each of the three dominant modes of SST variability in the Pacific is connected to the tropics and has a strong expression in extratropical SST and weather patterns. Beginning in the middle of 2013, the third mode of SST variability was two standard deviations positive and has remained so through January 2015.* ***This pattern is associated with high pressure in the northeast Pacific and low pressure and low surface temperatures over central North America.*** *A large ensemble of model experiments with observed SSTs confirms that SST anomalies contributed to the anomalous winter of 2014.*

Part of Figure 1 from Hartmann (2015), Showing the Third Mode of Sea Surface Temperature Variability Called the "North Pacific Mode"

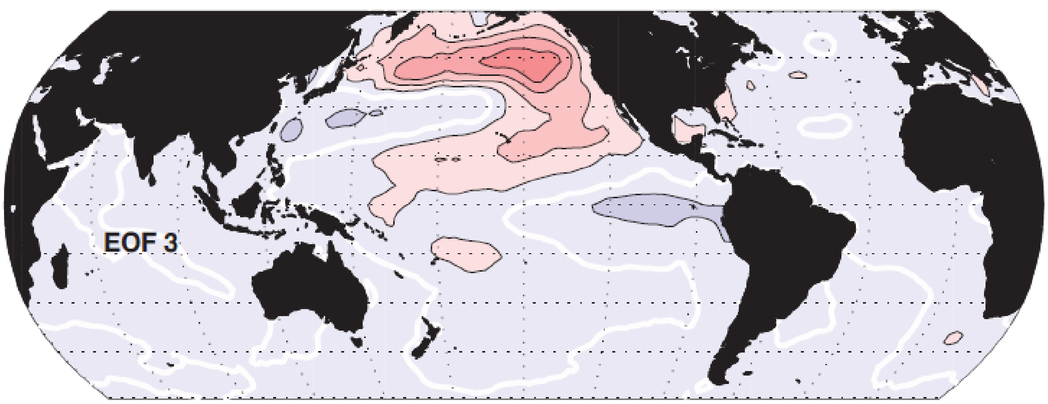


Figure GD-2-18

The “third mode of SST [sea surface temperature] variability” is shown in the map in my Figure GD-2-18, which is part of Figure 1 from Hartmann (2015). Also, the modeling experiments were performed with AMIP type models, meaning they were forced with the sea surface temperature data.

The Hartmann et al. (2015) was also previewed in the University of Washington press release titled ‘Warm blob’ in Pacific Ocean linked to weird weather across the U.S.

ON THE POCKET OF WARM WATER OFF OF SOUTHERN CALIFORNIA AND BAJA MEXICO

The pocket of warmer than normal sea surface temperatures off the coasts of Southern California and Baja Mexico is visible in the map presented above in Figure GD-2-10.

I've zoomed in on the Eastern North Pacific in Figure GD-2-19 and highlighted the coordinates used in the following discussion. We'll call that region the Baja Hotspot.

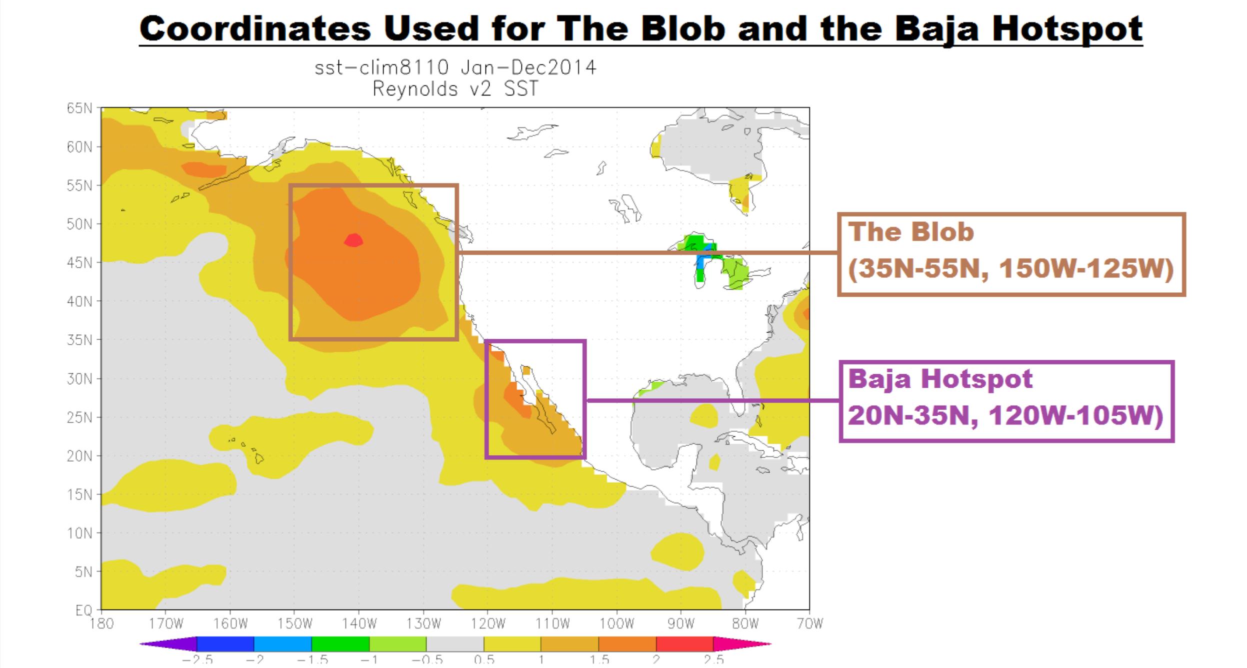


Figure GD-2-19

The average sea surface temperature anomalies for The Blob in 2014 were greater than the Baja Hotspot.

Both of those regions are known to warm during strong El Niño events, but:

- we didn't achieve strong El Niño conditions in 2014…strong El Niño conditions arrived in 2015…and
- the warming of The Blob and Baja Hotspot regions in response to El Niños is normally not that great.

To confirm the first of the bullet points, Figure GD-2-20 includes graphs of sea surface temperature anomalies for two NINO regions, from January 1, 2014 to October 7, 2015, based on the weekly Reynolds OI.v2 data here. The sea surface temperature anomalies for NINO regions are used by researchers to study the strength, frequency and duration of El Niño and La Niña events. The top graph is for the NINO3.4 region (5S-5N, 170W-120W). NOAA uses the sea surface temperature anomalies for the NINO3.4 region in their Oceanic NINO Index, a.k.a. ONI (but NOAA has and continues to use their monthly ERSST series of sea surface temperature data for ONI). The bottom graph is for the NINO3 region (5S-5N, 150W-90W). The Japan Meteorological Agency (JMA) uses the NINO3 region sea surface temperatures in their El Niño Outlook. See the NOAA map here for the locations of those NINO regions.

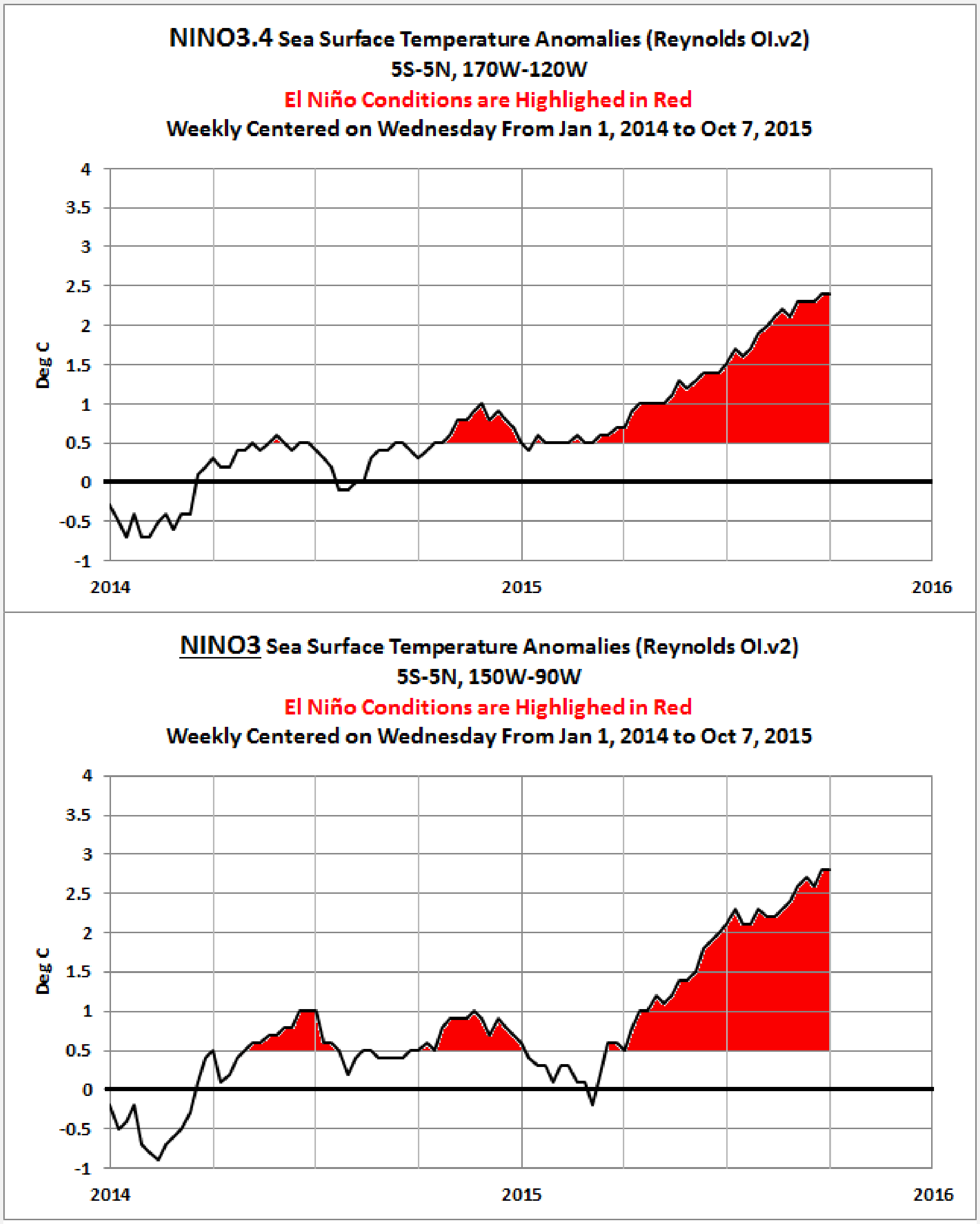


Figure GD-2-20

I've highlighted El Niño conditions in red in Figure GD-2-20, where El Niño conditions are defined as NINO region sea surface temperature anomalies equal to or greater than +0.5 deg C (+0.9 deg F). The threshold for moderate El Niño conditions is +1.0 deg C (+1.8 deg F) and the threshold for strong El Niño conditions is +1.5 deg C (2.7 deg F). (We'll confirm those thresholds later in Chapter 3.7 – Ocean Mode: El Niño and La Niña.)

As shown, weekly sea surface temperature anomalies for the NINO3 and NINO3.4 regions did occasionally reach the threshold of moderate El Niño conditions in 2014, but didn't warm to strong El Niño conditions until 2015.

Let's confirm the second bullet point from the discussion above.

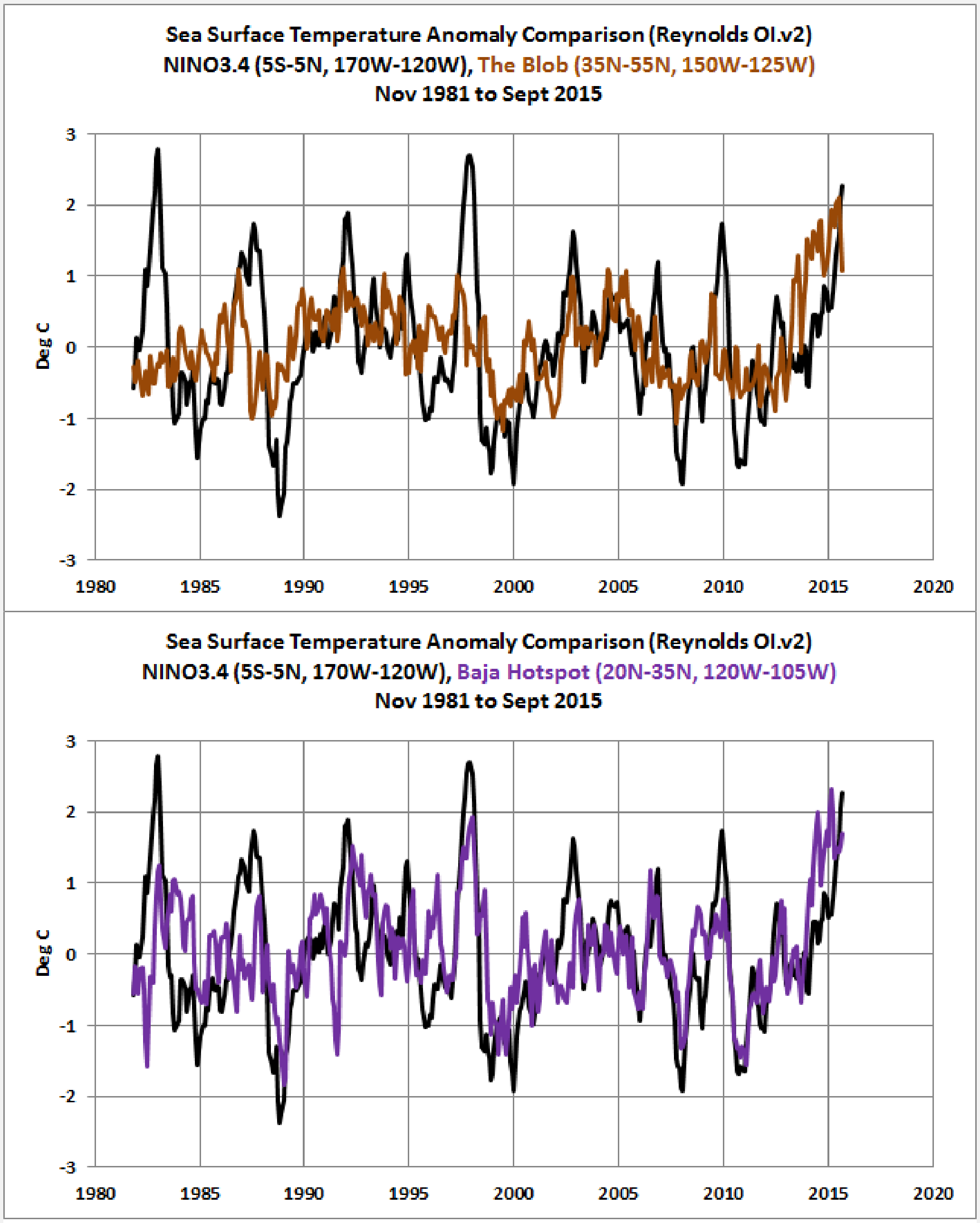


Figure GD-2-21

Figure GD-2-21 includes two comparison graphs of monthly Reynolds sea surface temperature anomalies. NINO3.4 region data (black curves) in both are used as a reference for the timing of El Niño events. The top graph also includes the sea surface temperature anomalies for The Blob (brown curve), while the bottom graph includes the data for the Baja Hotspot (purple curve). While the sea surface temperature anomalies for both regions do show responses to moderate and strong El Niños, the temperatures in those relatively small regions are very volatile, indicating they are strongly influenced by local weather. But one thing is certain: the recent upswings are unusual for both regions.

Starting in 2013, I've compared the data for all three regions in Figure GD-2-22.

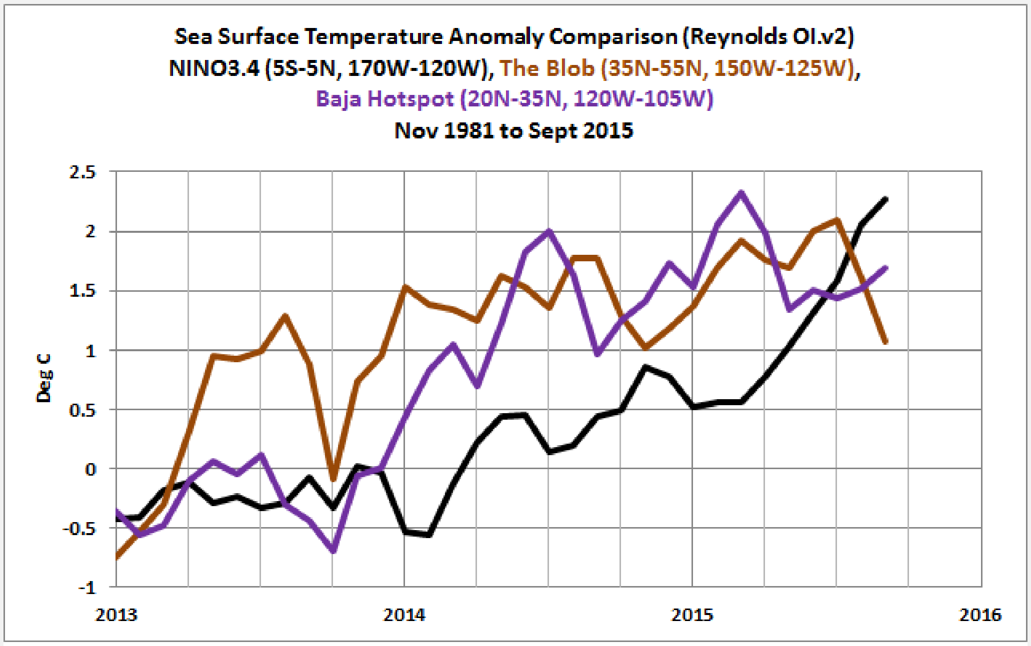


Figure GD-2-22

We can see that The Blob (brown curve) was the first to warm, beginning early in 2013. The Baja Hotspot began its climb late in 2013, well before the El Niño began to develop in 2014. This suggests that the initial warming in the Baja Hotspot was a response to The Blob, not the 2014 El Niño processes. That is not to say that El Niño processes did not contribute afterwards.

The Blob could have influenced the sea surface temperatures in the Baja Hotspot in a couple of ways. First, keep in mind that the California Current runs from north to south along the west coast of the U.S., so some of the warm water from The Blob should have been carried south by ocean circulation. Second, the ridge of high pressure associated with The Blob or the migrating warm water from it <u>may have</u> shifted wind patterns in Southern California and Baja Mexico, which in turn slowed the upwelling of cool waters along the coast. This is a possibility, but I have not found a paper that confirms this.

SUMMARY

Land surface temperatures were not at record high levels in 2014. The sea surface temperatures of no ocean basin, other than the North Pacific, were at record high levels in 2014. The western North Pacific was also not at record high temperatures. That leaves the eastern North Pacific.

The hotspot in the eastern North Pacific is known as The Blob.

The unusual warming event known as The Blob in the Eastern North Pacific:

- was responsible for the reported record-high global sea surface temperatures and global land+ocean surface temperatures in 2014, though the mainstream media failed to report that fact,
- was caused by a naturally occurring ridge of high pressure that prevented the sea surface temperatures of The Blob region from cooling normally during boreal winter months,
- along with the ridge of high pressure (known as the Ridiculously Resilient Ridge) was responsible for the warm temperatures and drought in the western United States and for the unusually cool temperatures in the eastern U.S.

Let's confirm that The Blob was not an effect of human-induced global warming. For this, we'll return to the University of Washington press release 'Warm blob' in Pacific Ocean linked to weird weather across the U.S. There they write:

> *Bond says that although the blob does not seem to be caused by climate change, it has many of the same effects for West Coast weather.*
>
> *"This is a taste of what the ocean will be like in future decades," Bond said. "It wasn't caused by global warming, but it's producing conditions that we think are going to be more common with global warming."*

Of course, the suggestions of future weather are simply speculation.

UPDATE

Meteorologists have recently (October 2015) reported that the Ridiculously Resilient Ridge has gone. The Blob also appears to be dissipating, but the warm surface waters associated with The Blob have simply been carried elsewhere by ocean currents. Unfortunately, there is still a large pocket of warmer-than-normal subsurface waters that was created by The Blob. Because of the pool of warm subsurface waters, The Blob could return.

2 – CLIMATE MODELS

The following chapters include general overviews of climate models and many of the commonly mentioned aspects of them. They are not detailed discussions of how they are climate models are programmed.

2.1 – Basic Overview of Climate Models

Simply put, climate models are numerical representations of the atmosphere, oceans, land surfaces, and other factors such as ice and vegetation. In the context of human-induced climate change, climate models are used to determine how much of the warming we've experienced **could be** attributed to man-made or natural causes, and they are used to study how climate **might** change in the future, assuming the modeled planets bear a relationship with Earth.

As noted in an earlier chapter, when you think of climate models, to keep them in perspective, maybe we should think of something we are more familiar with, something that we encounter every time we turn on our televisions, boot our computers or go to the movies. And that something is CGI or computer-generated imagery. CGI are images that are created using graphics software. CGI are attempts by computer modelers to replicate images of the real world or attempts to portray images of a fantasy world. Like CGI, climate models are not the real world. Climate models are attempts to portray Earth's climate with very complex computer software run on very expensive mainframe computers.

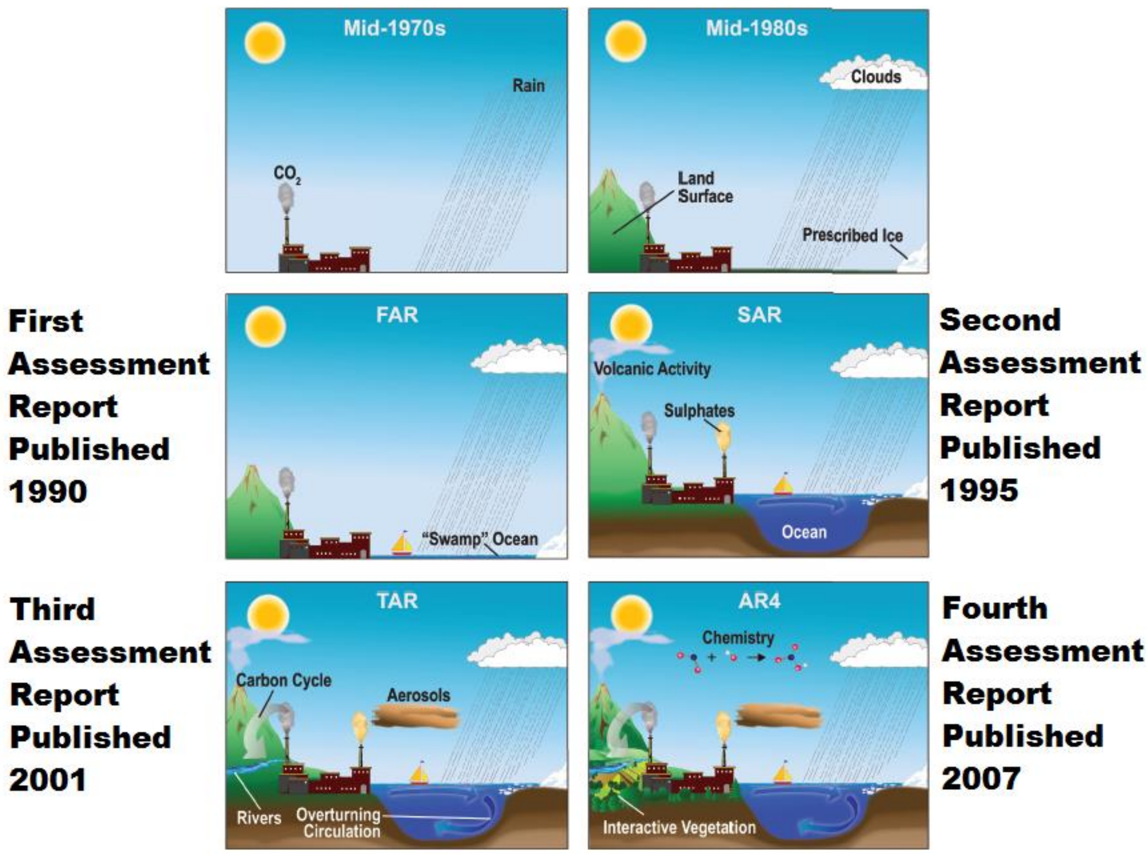
It must be kept in mind that the study of man's influence on climate is a relatively new field of science, especially the modelling efforts. My Figure 2.1-1 is an annotated version of Figure 1.2 from the IPCC's 4th Assessment Report. I've added the timings of the IPCC's 1st through 4th Assessment Reports.

The IPCC writes in Chapter 1 of their 4th Assessment Report (My boldface.)

> *During the last four decades, the rate at which scientists have added to the body of knowledge of atmospheric and oceanic processes has accelerated dramatically. As scientists incrementally increase the totality of knowledge, they publish their results in peer-reviewed journals. Between 1965 and 1995, the number of articles published per year in atmospheric science journals tripled (Geerts, 1999). Focusing more narrowly, Stanhill (2001) found that the climate change science literature grew approximately exponentially with a doubling time*

> *of 11 years for the period 1951 to 1997. Furthermore, 95% of all the climate change science literature since 1834 was published after 1951. Because science is cumulative, this represents considerable growth in the knowledge of climate processes and in the complexity of climate research.* ***An important example of this is the additional physics incorporated in climate models over the last several decades, as illustrated in Figure 1.2 [My Figure 2.1-1].***

Annotated Figure 1.2 from IPCC's 4th Assessment Report



Caption Reads: "*The complexity of climate models has increased over the last few decades. The additional physics incorporated in the models are shown pictorially by the different features of the modelled world.*"

Figure 2.1-1

But that illustration could be very misleading unless you're intimate with climate models. Example: In the upper-right-hand cell, mid-1980s, they show that clouds were added to climate models. But climate models still do not realistically simulate clouds, because there are many factors relating to clouds that are still unknown and because clouds are smaller than the resolution (the grid sizes) of the even the current models. The center right-hand illustration shows that climate models considered volcanic aerosols as early as 1995, but many of the models submitted to the CMIP3 archive for the IPCC's 4th Assessment Report in 2007 still did not include volcanic aerosols. Another example: in the lower-left-hand cell, they show that "overturning circulation" was added to the ocean models for the IPCC's Third Assessment Report (TAR) published in 2001. Unfortunately, the current generation of climate models still does not properly simulate the processes that can cause multidecadal variations in overturning circulation. We can see this with how poorly the models portray the surface temperatures of the oceans where the overturning circulation is a contributing factor to those surface temperatures. The other factor that illustration overlooks is that, now in 2015, we only have a little more than 10 years of globally complete temperature and salinity measurements within the oceans to depths of 2000 meters (about 6600 feet). Therefore, there is no long-term reference data against which the modelers can compare their simulations of those multidecadal variations in overturning circulation. ARGO floats now serve as the primary source of subsurface temperature and salinity measurements. We'll discuss the ARGO floats in much more detail in Part 2 (future). Those ARGO floats were funded about a decade and a half ago so that oceanographers and climate scientists **could begin to understand** how long-term, multidecadal ocean processes actually function.

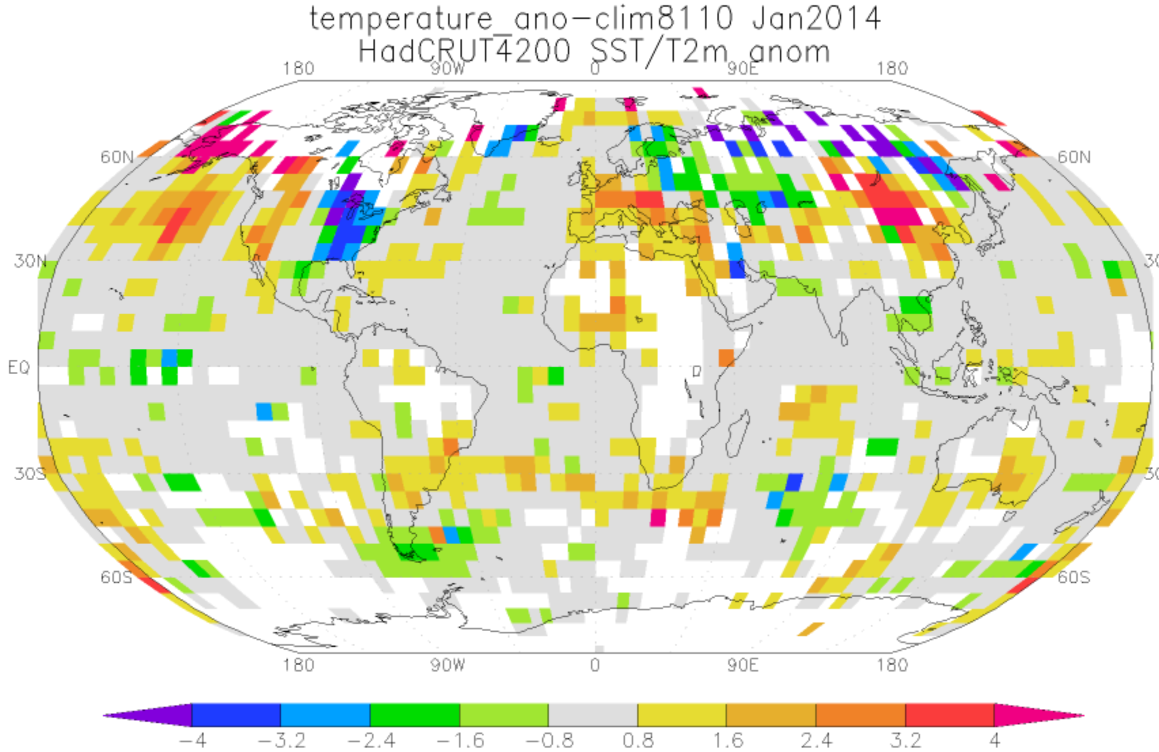
The other real head-scratcher is that the climate modelers have added all of the complexity to the models, but they still come up with the same basic answers they had decades ago with the less-complex models…with little change in the wide ranges of the answers. There are a number of simple reasons for this. Each time the modelers make the models more complex, they discover that there are more unknowns: known unknowns and unknown unknowns. One might also assume that modelers tweak the programs so that their new generation model provides answers that are similar to earlier generations.

The "additional physics incorporated into the climate models" has obviously made them more complex. In addition, the resolution of the models has become higher with each generation. The spatial resolution (the sizes of the grids) in climate models has improved, going from about 500 km (about 310 miles) for the IPCC's 1st Assessment Report to about 110 km (about 68 miles) for their 4th Assessment Report. (See Figure 1.4 from the IPCC's 4th Assessment Report.) And the models have increased the number of cells vertically. The models used in the 1st Assessment Report had 10 levels of atmosphere and a "slab" ocean, and by the 4th Assessment Report they had 30 levels each of atmosphere and ocean.

Let's discuss resolution, grids and levels for a moment. Figure 2.1-2 is a Robinson projection map of the January 2014 global surface temperature anomalies, with the

UKMO HADCRUT4 data. Notice how the data are presented in 5-degree latitude by 5-degree longitude grids. At the equator, a 5-degree longitude span equals a distance of 556 kilometers, and at 65N latitude, a 5-degree longitude span equals a distance of 235 kilometers (146 miles). (See the NOAA latitude/longitude distance calculator.)

HADCRUT4 Global Surface Temperature Data Are Presented in 5-Degree Latitude By 5-Degree Longitude Grids



Map Created at KNMI Climate Explorer

Figure 2.1-2

Let's assume for the sake of discussion that an early generation of climate models was formatted in the same way, in 5-degree latitude by 5-degree longitude grids. The computer model runs through its calculations for each grid, and each grid communicates information to the grids on each of its sides: north, south, east and west. The atmosphere and oceans also have altitude and depth, so we have to consider height. And we'll call that 3-dimensional portion a cell. The modelers add layers of atmosphere and layers of ocean. So each cell also communicates with the one above and below.

As noted earlier, the modelers have heightened the resolution over the past decades. They've done this by decreasing the size of the grids horizontally, which creates many more grids, and also by increasing the number of levels (layers) of atmosphere so that each level has a shorter height or depth. The grid sizes and the number of layers were in some respects dictated by the speed of the computers. As computers grew faster, they were able to perform many more calculations during the same amount of time.

But have the additional physics and higher resolution helped the predictions of future climate? If we look at the models in very broad terms, the answer is no. Those predictions have remained about the same over the years. With all of the additional complexity, climate models still predict global surface temperatures will warm by “x” amount by 2100, sea levels will rise “y” centimeters by then, some parts of the Earth will benefit from additional precipitation, while others will experience drought, etc. And there have been, and there continue to be, broad ranges in those predictions. Some climate models show little warming, while others show warming increasing much more rapidly. Some models show additional precipitation in specific regions, while others, for example, show increased drought for the same regions. But in general, the predictions of future climate from the early generation of models are not especially different than they were decades ago.

The wide ranges of climate model predictions have led to some wildly misleading claims. About 5 years ago, whenever there was an extreme weather event, we commonly heard the phrase “consistent with climate models”. It didn’t matter where, or when, or what had happened, it was “consistent with climate models”. The backlash was predictable. People began to realize that if everything was “consistent with climate models” then climate models really had no value. A June 2008 opinion in the *National Post* titled Nothing 'wacky' about the weather summed the problem nicely:

> *If all weather events are consistent with climate models, then no current weather events serve as any useful indicator of climate change or as a sign that climate change is happening.*

Let’s rephrase that: If every weather event is consistent with climate models, then the models can never be verified or disproven by observations or experiments, and if you can’t verify or disprove a model, then the model has questionable purpose or value.

While the “consistent with climate models” fallacy has lost momentum, the mainstream media continue to try to link weather events to human-induced global warming. We’ve already presented weather event-related data in the book and shown that extreme weather has not gotten worse.

2.2 – Different Types of Climate Models

Many people are aware of the climate models that are used to simulate past climate and to predict what climate may be like in the future based on projections of future emissions of man-made greenhouse gases. (They're aware of them, but they may or may not understand them.) There are dozens of research agencies around the world that have created very complex, coupled ocean-atmosphere models that are used for that purpose. The research agencies share information and programs so that the models are a hodgepodge of shared software and programs that were generated in-house by the individual research agencies.

In more recent decades, for each generation of models, researchers have prepared an archive for storing the outputs of those specific models, and each archive is called a phase of the Coupled Model Intercomparison Project (CMIP). This allows scientists (and laymen) from all over the globe to study the outputs of those models.

As the models changed with time, becoming more complex, the archives have been updated to include new generations of climate models. Recent generations also coincide with and are used in the editions of the Assessment Reports from the Intergovernmental Panel on Climate Change. More specifically, the CMIP archive phase 3 (CMIP3) was used in the IPCC's 4th Assessment Report (AR4) published in 2007, and the CMIP5 archive was used for the IPCC's 5th Assessment Report (AR5), which was published in 2013/2014.

Because climate scientists don't know for certain the rates at which man-made greenhouse gases will be emitted in the future, the models simulate future climate based on a number of "what if" scenarios. That is, for example, they'll simulate future climate if greenhouse gas emissions continue to climb unceasingly (a kind of worst-case scenario), and they'll simulate future climate if there are cutbacks in emissions. And to assure that the modeling groups are simulating the same future scenarios, future factors like greenhouse emissions and changes in the output of the sun are standardized for each scenario.

SPECIALIZED RESEARCH

For very specific research, sometimes modelers will change the inputs used in a climate model to study a particular response or aspect of their models. Scientific studies are then written about these "custom" scenarios. They should not be confused with the simulations using the standard "CMIP" scenarios, upon which the IPCC reports are written.

OTHER TYPES OF CLIMATE MODELING EFFORTS

AMIP Models

In addition to models stored in the CMIP archives, there are other types of climate models or modeling efforts. One example is the models submitted to and stored in the Atmospheric Model Intercomparison Project (AMIP). In this instance, the models do not simulate ocean processes or sea ice; data for those metrics are used as inputs to the models. This allows modelers to see how well the atmospheric portion of the models simulates responses to changes in the oceans and sea ice. Some modeling groups use the AMIP simulations to fine tune the atmospheric side of the models before they couple them with their ocean models for the CMIP simulations. We'll discuss the tuning of climate models in a later chapter.

Reanalyses

Climate models are also used to create what is known as a reanalysis. Reanalyses are prepared because there are many variables that still cannot be measured with instruments—or for which we have very little observations-based data. For example, for decades, satellites have been used to measure that amount of solar radiation reaching the top of Earth's atmosphere, but the Earth is warmed by how much solar radiation reaches the land surfaces and penetrates into the oceans. We have had devices to measure the amount of solar radiation reaching land surfaces for some time now. In fact, one dataset from one location that we'll discuss in the upcoming Part 2 of this book extends back to the 1920s. Unfortunately, there are few to no of those sensors bobbing around on the ocean surface, and since the oceans cover 70% of the surface of the planet, that's a tremendous gap in our understanding of what has warmed the planet. So modelers will input whatever relevant data is available and allow the climate models to "fill in the blanks". These reanalyses have been prepared for the atmosphere and for the oceans, and even the results of reanalyses can differ drastically.

The National Center for Atmospheric Research (NCAR) presents the limitations of reanalyses at the end of the Summary of their webpage titled Atmospheric Reanalysis: Overview and Comparison Tables. There they write (my boldface):

> *Key Limitations:*
>
> - ***Reanalysis data sets should not be equated with "observations" or "reality"***
> - *The changing mix of observations, and biases in observations and models, can introduce spurious variability and trends into reanalysis output*

- *Observational constraints, and therefore reanalysis reliability, can considerably vary depending on the location, time period, and variable considered*

Yet you will find papers presenting the outputs of a reanalysis as though they equate to “observations” or “reality”.   Those studies are commonplace.

There are numerous other types of climate models but the outputs of the CMIP-based models and the reanalyses are referred to and presented in this book, so we’ll end the discussion there.

2.3 – Climate Forcings Drive Climate Models

The term "climate forcing" is most often used to describe information that serves as inputs to climate models; that is, they are the inputs that force the numerical climate in the models to change with time. Because the forcings change with time, climate in the models also change with time. It may be easier to think of a climate forcing as any outside factor (input) that causes change in modeled climate.

Some of the forcings are based on observations-based data; that is, they are based on measurements obtained from instruments. Other forcings are based on estimates derived from research. Those estimates are necessary because there are factors that can influence climate for which we have few, if any, long-term measurements. Additionally, the forcings must also be distributed around the modeled globe and must also be varied for the changes of seasons and the like within the models. Unfortunately, because many of the forcings are not based on observations, or they're based on few samples, there is a lot of uncertainty about them and how they are distributed around the globe.

Some factors like greenhouse gases are considered positive forcings because they contribute to the warming of our planet. And there are negative forcings, such as aerosols ejected into the stratosphere by explosive volcanic eruptions, which cool the planet by blocking sunlight from reaching the Earth's surface.

There are numerous forcings that serve as inputs to climate models. Man-made forcings include greenhouse gases: carbon dioxide, methane, nitrous oxide and fluorinated gases (chlorofluorocarbons). And there are other man-made factors such as black carbon (basically soot), reflective aerosols (tiny particles in the air that reflect sunlight back into space), soil or dust, and land cover changes (like adding buildings and blacktop-covered roads where grasslands or forest once existed). The principal natural forcings are solar irradiance (sunlight) and sunlight-blocking aerosols from explosive volcanic eruptions.

Figure 2.3-1 shows a time-series graph from 1880 to 2010 of the climate forcings that serve as inputs to the climate models from the NASA Goddard Institute for Space Studies (GISS). The units are in watts per square meter (watts/m^2). They're from the Forcings in GISS Climate Model webpage, specifically the table here. As shown, some of the forcings are positive with time—with the forcing from well-mixed man-made greenhouse gases serving as the greatest positive forcing in recent years. On the other hand, there are negative forcings such as Reflective Tropospheric Aerosols that counteract (work against) the positive forcings. The large downward spikes in the

Stratospheric Aerosols are caused by explosive volcanic eruptions, like Mount Pinatubo in 1991, El Chichon in 1982 and Krakatoa in 1883.

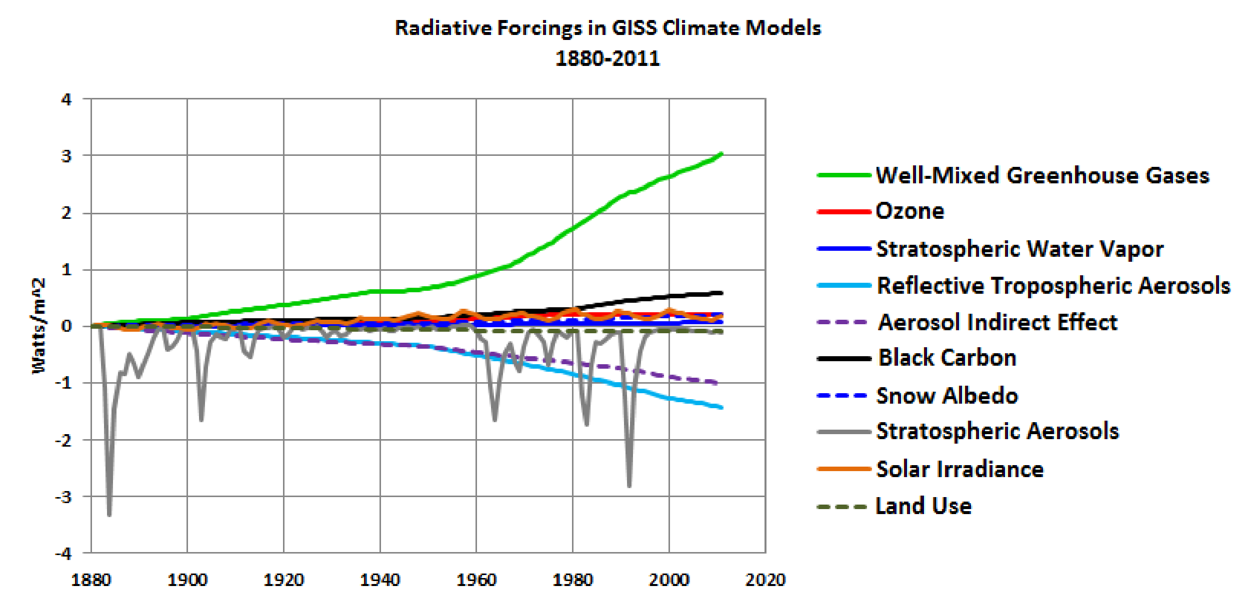


Figure 2.3-1

For further information about the individual forcings, see the following webpages prepared by GISS. They also list the scientific studies that serve as references for the estimates of the forcing values.

- Well-Mixed Greenhouse Gases
- Solar Irradiance
- Tropospheric Aerosols
- Stratospheric Aerosols

Keep in mind that many of the forcings are estimates (educated guesses)—that there are no instrument-based measurements for many of those forcings as we travel back in time. Also refer to the papers linked to those GISS webpages. Those estimates are not without their uncertainties.

A CLOSER LOOK

A few things stand out quite plainly in the above graph. First, the forcing from well-mixed man-made greenhouse gases (the fluorescent green curve that increases most with time) are the dominant positive forcing. Second, on the flip side of the coin are the two dominant negative forcings that show a gradual change with time: the reflective tropospheric aerosols (light blue curve) and the aerosol indirect effect (dashed purple curve). Third, the two aerosol forcings oppose (counteract) the effects of the well-mixed greenhouse gases.

Figure 2.3-2 compares the forcing from well-mixed man-made greenhouse gases with the forcings from reflective tropospheric aerosols and aerosol indirect effect. Also shown (the black curve) are the net effects of those three forcings, which is the sum of those three individual forcings. Notice how the curve of the net forcing of those three dominant forcings is relatively flat until about 1970. That indicates the aerosols blocked the effects of greenhouse gases and kept them from causing global warming, according to the model inputs. Then, after the 1970s, the greenhouse gases overcame the opposing effects of the aerosols, and, according to the forcings, man-made global warming began. In other words, the hypothesis of human induced global warming—and the speculation that greenhouse gases became dominant in the late 20th Century—depend on the "balance" of greenhouse gases and aerosols within the models.

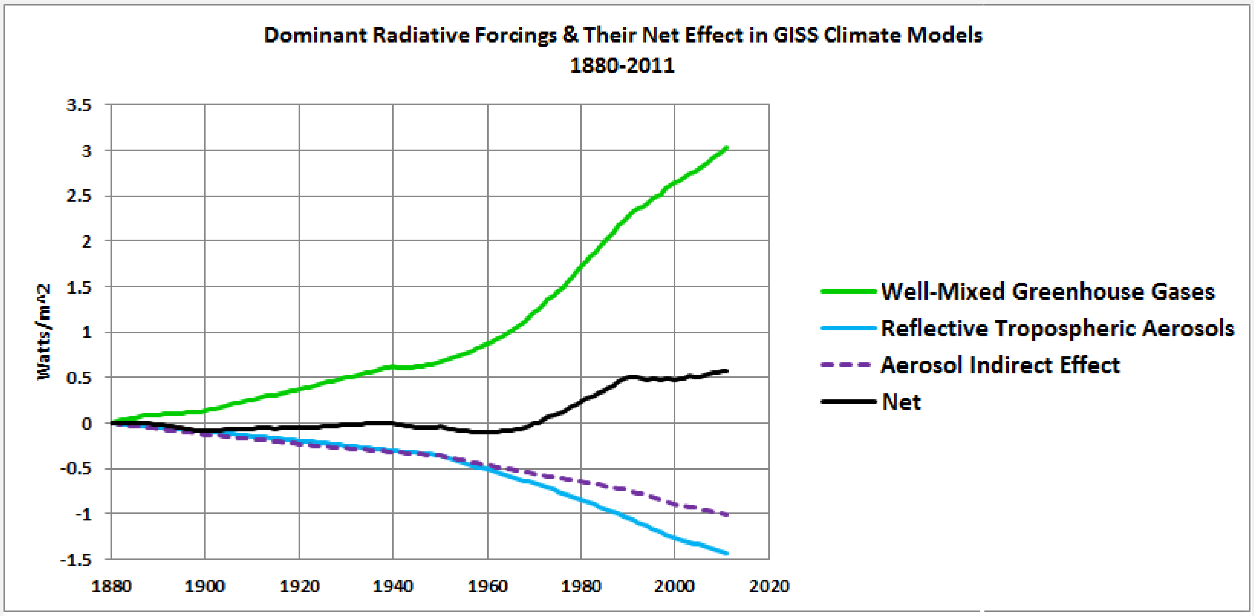


Figure 2.3-2

Unfortunately, very little is still known about aerosols…and how they interact with clouds. Refer to [Chapter 7: Clouds and Aerosols of the 5th Assessment Report from the Intergovernmental Panel on Climate Change](). Under the heading of "Progress in Understanding", they write (my boldface):

> Climate-relevant aerosol processes are better understood, and climate-relevant aerosol properties better observed, than at the time of AR4. However, **the representation of relevant processes varies greatly in global aerosol and climate models and it remains unclear** what level of sophistication is required to model their effect on climate. Globally, between 20 and 40% of aerosol optical depth (***medium confidence***) and between one quarter and two thirds of cloud condensation nucleus concentrations (***low confidence***) are of anthropogenic origin.

Translation: There is still very little agreement within specialized aerosol models and within climate models about the effects of aerosols on climate. And climate scientists have little confidence in how much of the aerosols are furnished by man-made (or natural) sources or how much of the aerosol effects within clouds are caused by man-made (or natural) sources.

This discussion is further expanded in Anderson et al. (2003) Climate Forcing by Aerosols – a Hazy Picture. It includes (my boldface):

> *Anthropogenic aerosol forcings arise from multiple aerosol components and various forcing mechanisms. The sum of these forcings has been calculated by two independent methods. First, forward calculations are based on knowledge of the pertinent aerosol physics and chemistry. Second,* ***inverse calculations infer aerosol forcing from the total forcing required to match climate model simulations with observed temperature changes****.*

In other words, looking at the second (highlighted) method, the modelers basically adjust the impacts of the aerosol forcings so that the models match the surface temperature record. If the sensitivity of a climate model is too high to greenhouse gases and shows too much warming during the 20th Century with respect to observed surface temperatures, then the modelers offset that high sensitivity by increasing the effects of aerosols. Conversely, if another climate model was less sensitive to greenhouse gases, it would require less offsetting effects from aerosols. We can take home a few messages from that: First, the modelers do not know how sensitive Earth's surface temperatures are to man-made greenhouse gases. Second, many people believe the climate science community argue for high climate sensitivities in order to keep the monies flowing to their research.

For informational purposes: Figure 2.3-3 compares the net of the dominant GISS forcings (well-mixed greenhouse gases, reflective tropospheric aerosols and aerosol indirect effect) with the net of the others, excluding the Stratospheric Aerosols from explosive volcanic eruptions. The explosive volcanic eruption forcings add nothing to the long-term trend and mask the gradual "linear" increase of the other forcings. The 11-year cycle in the other forcings is a response to the solar cycle that exists in the solar forcings. Notice how there is a slight bowing to the curve of the net other forcings, but it's very slight compared to the drastic change that occurs in the curve of the net dominant forcings.

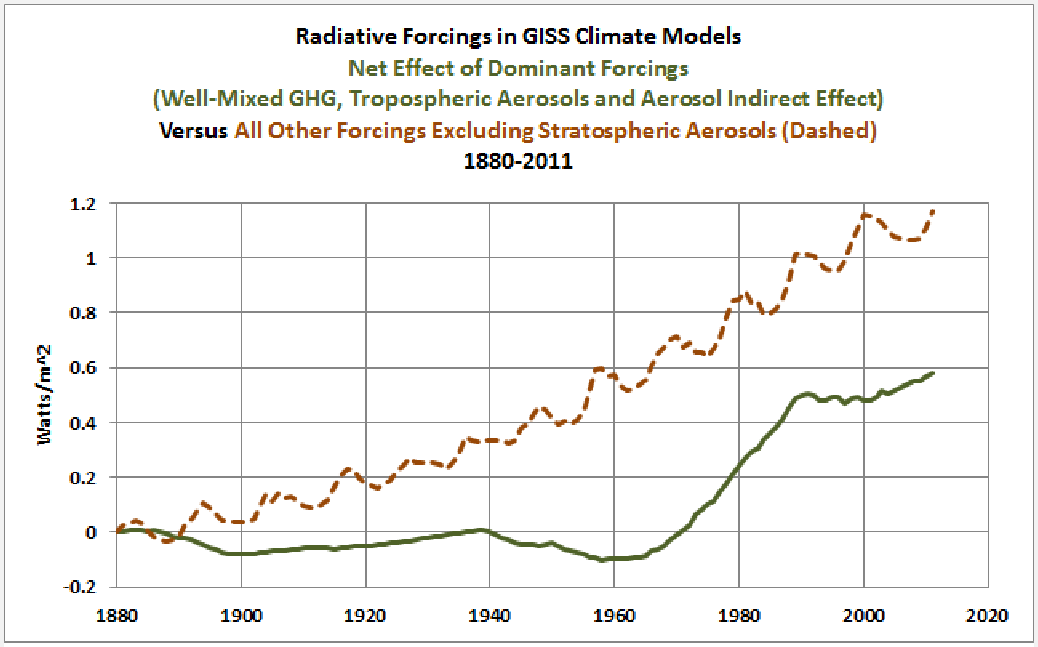


Figure 2.3-3

Please do not misinterpret the above illustration. It does not show that the other forcings (excluding the stratospheric aerosols) have a greater effect than well-mixed greenhouse gases. Recall, for the net effect of the dominant radiative forcings, the reflective tropospheric aerosols and aerosol indirect effect have been subtracted from the well-mixed greenhouse gases.

Bottom line: The belief that man-made greenhouse gases became the dominant forcing in the late 20th Century is based primarily on poor estimates of aerosols, the effects of which are largely unknown by climate modelers.

FORCINGS VERSUS CLIMATE MODEL OUTPUTS

The net of all of the climate forcings, including stratospheric (volcanic) aerosols, are compared to the model simulations of global surface temperature anomalies in Figure 2.3-4. The climate models are represented by the model mean of the models stored in the CMIP5 archive, using the historic and RCP6.0 scenarios. All six of the GISS Model-E simulations of global surface temperature for that scenario (GISS-E2-H P1, GISS-E2-H P2, GISS-E2-H P3, GISS-E2-R P1, GISS-E2-R P2, GISS-E2-R P3) are represented by the dashed dark-green curve. And as a reference, all of models stored in the CMIP5 archive for that scenario are shown with the dashed red curve. The forcings and model outputs have been referenced to the base years of 1880-2011 (full term) for anomalies.

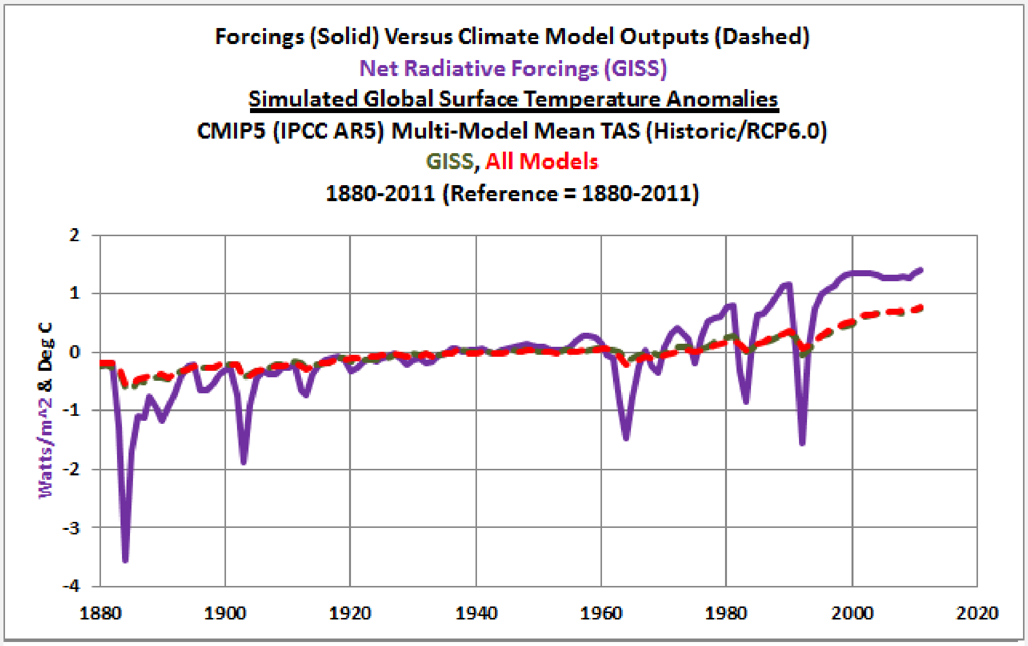


Figure 2.3-4

The forcings are presented in watts per square meter (watts/m^2) and the climate model simulations of global surface temperature are presented in deg C. With the different units, the relationships between the inputs to outputs are difficult to see. To put them on a common playing field, the forcings and model outputs have been standardized (divided by their standard deviations) in Figure 2.3-5. That leaves them without units for the vertical axis (y-axis) but the visual comparison is easier.

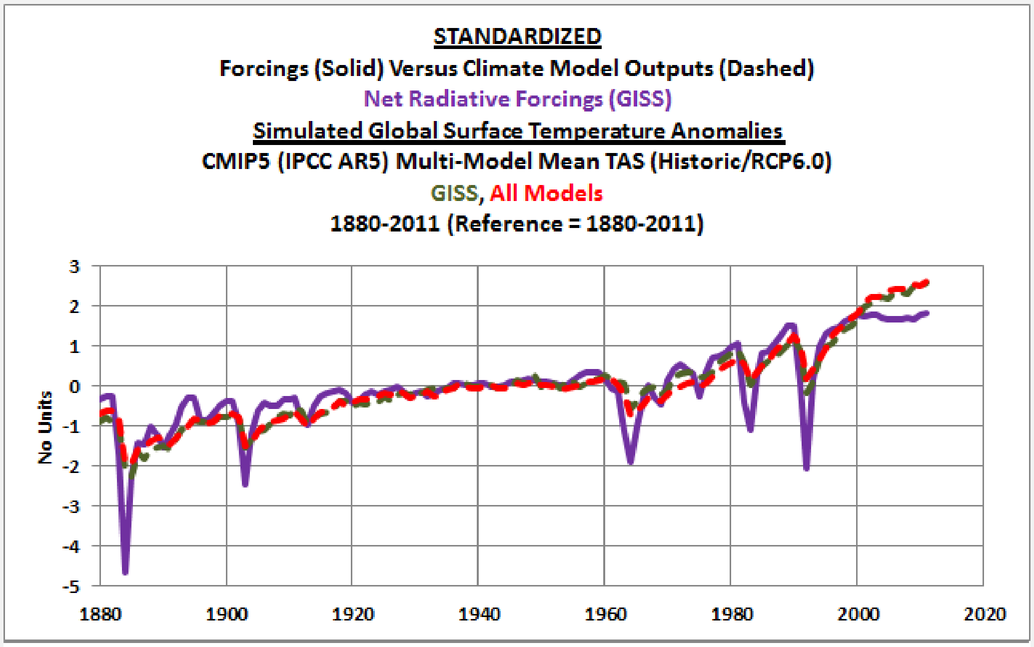


Figure 2.3-5

There are a couple of things that stand out. First, the models suppress the sharp dips in forcings caused by the explosive volcanic eruptions. Second, since about 1998 the forcings have been flat, but the simulated global surface temperatures continue to climb. This is easier to see if we zoom in on the period starting in 1998. See Figure 2.3-6.

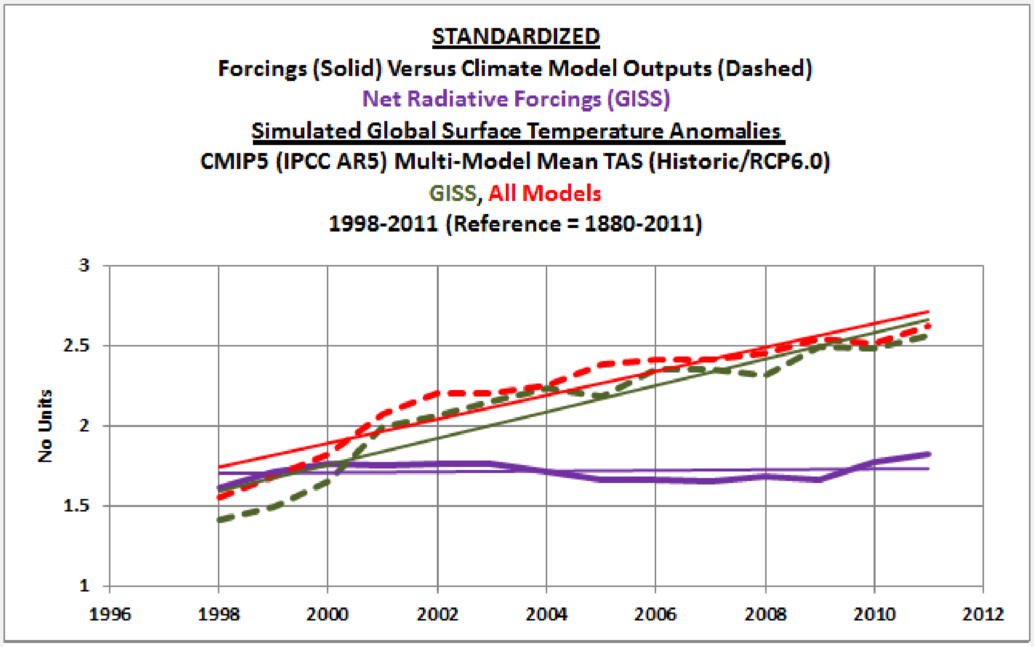


Figure 2.3-6

1998 is one of the commonly used start years for the slowdown or halt in global warming. The GISS models continue to show warming during this period, but they are apparently not being forced to do so. If we assume the other models are using similar forcings, then they, too, continue to show warming without being forced.

Climate forcings serve as the inputs that drive climate models. As such, forcings are a critical component of climate models. As will be revealed in a later chapter, climate models, quite remarkably, do not even consider observed trends in forcings.

SUMMARY

Climate forcings are used to drive climate models. They too have lots of uncertainties. The hypothesis of human induced global warming—and the speculation that greenhouse gases became dominant in the late 20th Century—depend on the "balance" of greenhouse gases and aerosols within the models, but there is still very little agreement within climate models about the effects of aerosols on climate.

2.4 – Emissions Scenarios

Climate scientists rely on climate models to simulate what climate might be like in the future. The grand assumption is, of course, that the climate models simulate Earth's climate properly.

Unfortunately, climate scientists do not have crystal balls through which they can divine future emissions of man-made greenhouse gases. Yet they're trying to answer a very basic question: if the emissions of greenhouse gases increase, what will climate be like in the future, assuming their models correctly simulate Earth's climate? So they create a number of what-if situations where man-made greenhouse gases increase at different rates. Those situations are called "emission scenarios". For the 5th Assessment Report, the IPCC used the term "Representative Concentration Pathway (RCP)" for a scenario.

INTRODUCTION TO EMISSIONS SCENARIOS

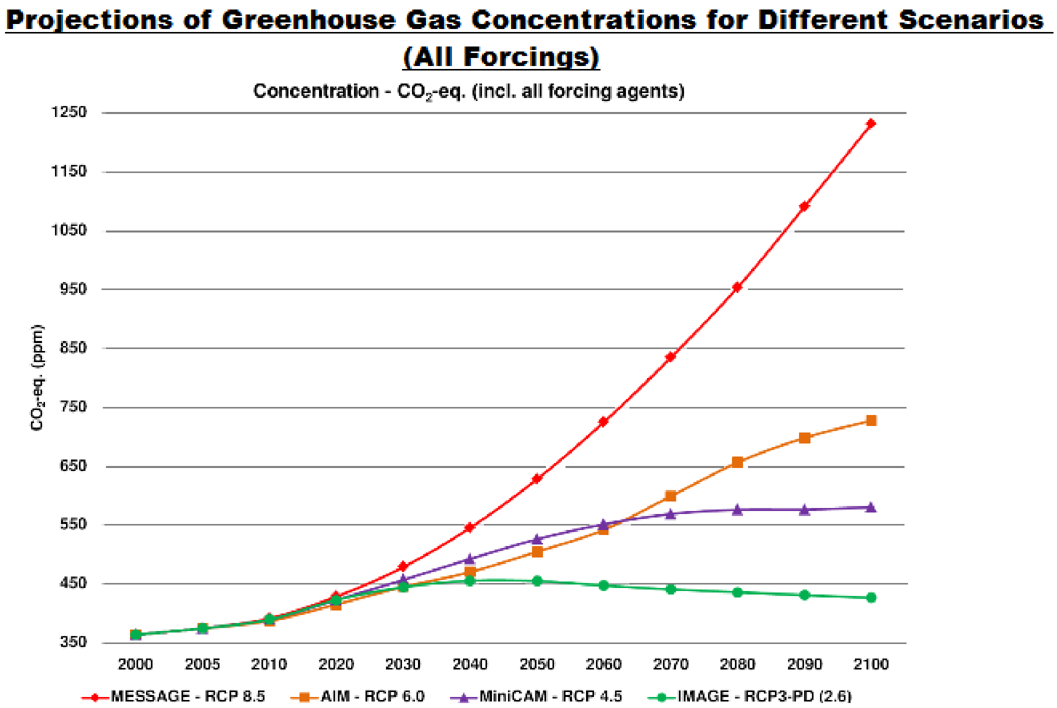
The World Meteorological Organization (WMO) has an introductory discussion of Representative Concentration Pathway (RCP) on their **Emissions Scenario** webpage (Table 1.1 is their numbering):

> *The Representative Concentration Pathways (RCP) are based on selected scenarios from four modelling teams/models working on integrated assessment modelling, climate modelling, and modelling and analysis of impacts. The RCPs are not new, fully integrated scenarios (i.e., they are not a complete package of socioeconomic, emissions, and climate projections). They are consistent sets of projections of only the components of radiative forcing (the change in the balance between incoming and outgoing radiation to the atmosphere caused primarily by changes in atmospheric composition) that are meant to serve as input for climate modelling. Conceptually, the process begins with pathways of radiative forcing, not detailed socioeconomic narratives or scenarios. Central to the process is the concept that any single radiative forcing pathway can result from a diverse range of socioeconomic and technological development scenarios. Four RCPs were selected, defined and named according to their total radiative forcing in 2100 (see table below). Climate modellers will conduct new climate model experiments using the time series of emissions and concentrations associated with the four RCPs, as part of the preparatory phase for the development of new scenarios for the IPCC's Fifth Assessment Report (expected to be completed in 2014) and beyond.*

Table 1.1: Overview of Representative Concentration Pathways (RCPs)

RCP 8.5	*Rising radiative forcing pathway leading to 8.5 W/m² in 2100.*
RCP 6	*Stabilization without overshoot pathway to 6 W/m² at stabilization after 2100*
RCP 4.5	*Stabilization without overshoot pathway to 4.5 W/m² at stabilization after 2100*
RCP 3-PD2	*Peak in radiative forcing at ~ 3 W/m² before 2100 and decline*

Figure 2.4-1 is a graph of projections of future emission scenarios used by the IPCC for their recent 5th Assessment Report. All man-made climate forcings are included and they have all been converted so that they are equal to concentrations of carbon dioxide (a.k.a. CO_2 equivalent) for the graph. The graph is available through the Wikipedia Representative Concentration Pathways (RCP) webpage. The worst-case scenario shown (RCP8.5 in red) has greenhouse gas emissions continuing to grow at an accelerated pace through the year 2100. And there are three other scenarios in which greenhouse gas concentrations in the atmosphere grow at much lower rates…even stop increasing in the case of RCP2.6 (green).



Source:
http://en.wikipedia.org/wiki/File:All_forcing_agents_CO2_equivalent_concentration.png

Figure 2.4-1

Further descriptions of Representative Concentration Pathways can be found at the RCP database Version 2.0.5 website. A few noteworthy quotes follow. Under the heading of "Characteristics and guidance", they note (my boldface):

> *The RCPs are named according to their 2100 radiative forcing level as reported by the individual modeling teams. The radiative forcing estimates are based on the forcing of greenhouse gases and other forcing agents - but does not include direct impacts of land use (albedo) or the forcing of mineral dust.*
>
> ***The RCPs are not forecasts or boundaries for potential emissions, land-use, or climate change. They are also not policy prescriptive in that they were chosen for scientific purposes to represent the span of the radiative forcing literature at the time of their selection and thus facilitate the mapping of a broad climate space. They therefore do not represent specific futures with respect to climate policy action (or no action) or technological, economic, or political viability of specific future pathways or climates.***
>
> *The RCPs are four independent pathways developed by four individual modeling groups.* ***The socioeconomics underlying each RCP are not unique; and, the RCPs are not a set or representative of the range of potential assumptions. For instance, the RCPs with lower radiative forcing (RCP 6.0, RCP 4.5 and***

> ***RCP 2.6) are not derived from those with higher radiative forcing (RCP 8.5, or even RCP 6.0). The differences between the RCPs can therefore not directly be interpreted as a result of climate policy or particular socioeconomic developments.*** *Any differences can be attributed in part to differences between models and scenario assumptions (scientific, economic, and technological). This is in particular relevant for scenario elements that are only indirectly coupled to the radiative forcing targets such as land use/land cover and air pollutant emissions.*

What I've boldfaced above is very important. (1) The RCP emission scenarios are "not policy prescriptive". That is, the RCP emission scenarios are not intended to serve as recommendations or references for climate-related policies. (2) The RCP emission scenarios "do not represent specific futures with respect to climate policy action (or no action)…" (3) "The differences between the RCPs can therefore not directly be interpreted as a result of climate policy or particular socioeconomic developments."

And the following are portions of the discussions under the heading of "Information on individual RCPs" with links to the citations:

> ***RCP 2.6:***
>
> *The RCP 2.6 is developed by the IMAGE modeling team of the Netherlands Environmental Assessment Agency. The emission pathway is representative for scenarios in the literature leading to very low greenhouse gas concentration levels. It is a so-called "peak" scenario: its radiative forcing level first reaches a value around 3.1 W/m2 mid-century, returning to 2.6 W/m2 by 2100. In order to reach such radiative forcing levels, greenhouse gas emissions (and indirectly emissions of air pollutants) are reduced substantially over time. The final RCP is based on the publication by Van Vuuren et al. (2007)…*
>
> - *van Vuuren, D., M. den Elzen, P. Lucas, B. Eickhout, B. Strengers, B. van Ruijven, S. Wonink, R. van Houdt, 2007. Stabilizing greenhouse gas concentrations at low levels: an assessment of reduction strategies and costs. Climatic Change, doi:10.1007/s/10584-006-9172-9.*
>
> ***RCP 4.5:***
>
> *The RCP 4.5 is developed by the MiniCAM modeling team at the Pacific Northwest National Laboratory's Joint Global Change Research Institute (JGCRI). It is a stabilization scenario where total radiative forcing is stabilized before 2100 by employment of a range of technologies and strategies for reducing greenhouse gas emissions. The scenario drivers and technology*

options are detailed in Clarke et al. (2007). Additional detail on the simulation of land use and terrestrial carbon emissions is given by Wise et al (2009)…

- *Clarke, L., J. Edmonds, H. Jacoby, H. Pitcher, J. Reilly, R. Richels, 2007. Scenarios of Greenhouse Gas Emissions and Atmospheric Concentrations. Sub-report 2.1A of Synthesis and Assessment Product 2.1 by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. Department of Energy, Office of Biological & Environmental Research, Washington, 7 DC., USA, 154 pp.*
- *Smith, S.J. and T.M.L. Wigley, 2006. Multi-Gas Forcing Stabilization with the MiniCAM. Energy Journal (Special Issue #3) pp 373-391.*
- *Wise, MA, KV Calvin, AM Thomson, LE Clarke, B Bond-Lamberty, RD Sands, SJ Smith, AC Janetos, JA Edmonds. 2009. Implications of Limiting CO2 Concentrations for Land Use and Energy. Science. 324:1183-1186. May 29, 2009.*

RCP 6.0:

The RCP 6.0 is developed by the AIM modeling team at the National Institute for Environmental Studies (NIES), Japan. It is a stabilization scenario where total radiative forcing is stabilized after 2100 without overshoot by employment of a range of technologies and strategies for reducing greenhouse gas emissions. The details of the scenario are described in Fujino et al. (2006) and Hijioka et al. (2008)…

- *Fujino, J., R. Nair, M. Kainuma, T. Masui, Y. Matsuoka, 2006. Multi-gas mitigation analysis on stabilization scenarios using AIM global model. Multigas Mitigation and Climate Policy. The Energy Journal Special Issue.*
- *Hijioka, Y., Y. Matsuoka, H. Nishimoto, M. Masui, and M. Kainuma, 2008. Global GHG emissions scenarios under GHG concentration stabilization targets. Journal of Global Environmental Engineering 13, 97-108.*

RCP 8.5:

The RCP 8.5 is developed by the MESSAGE modeling team and the IIASA Integrated Assessment Framework at the International Institute for Applies Systems Analysis (IIASA), Austria. The RCP 8.5 is characterized by increasing greenhouse gas emissions over time representative for scenarios in the literature leading to high greenhouse gas concentration levels. The underlying scenario drivers and resulting development path are based on the A2r scenario detailed in Riahi et al. (2007)…

- *Riahi, K. Gruebler, A. and Nakicenovic N.: 2007. Scenarios of long-term socio-economic and environmental development under climate stabilization. Technological Forecasting and Social Change 74, 7, 887-935.*

A much more detailed description of RCP8.5 can be found in Riahi et al. (2011) RCP 8.5—A scenario of comparatively high greenhouse gas emissions.

RCP SCENARIO FORCINGS DRIVE CLIMATE MODELS

The RCP emission scenarios, of course, include forcings which served as inputs to the climate models stored in the CMIP5 archive. The climate models then produce projections of future changes in climate-related variables such as surface temperature and precipitation. Figure 2.4-2 presents the multi-model ensemble-member means (the averages of all of the individual simulations) for the four RCP emission scenarios from the CMIP5-archived models. As one would expect, the projected warming depends on the projections of man-made greenhouse emissions. Refer back to Figure 2.4-1. Note that the climate model outputs have been zeroed at the year 2014 to make it easier to determine the projected rises in global surface temperatures from the present time through 2100.

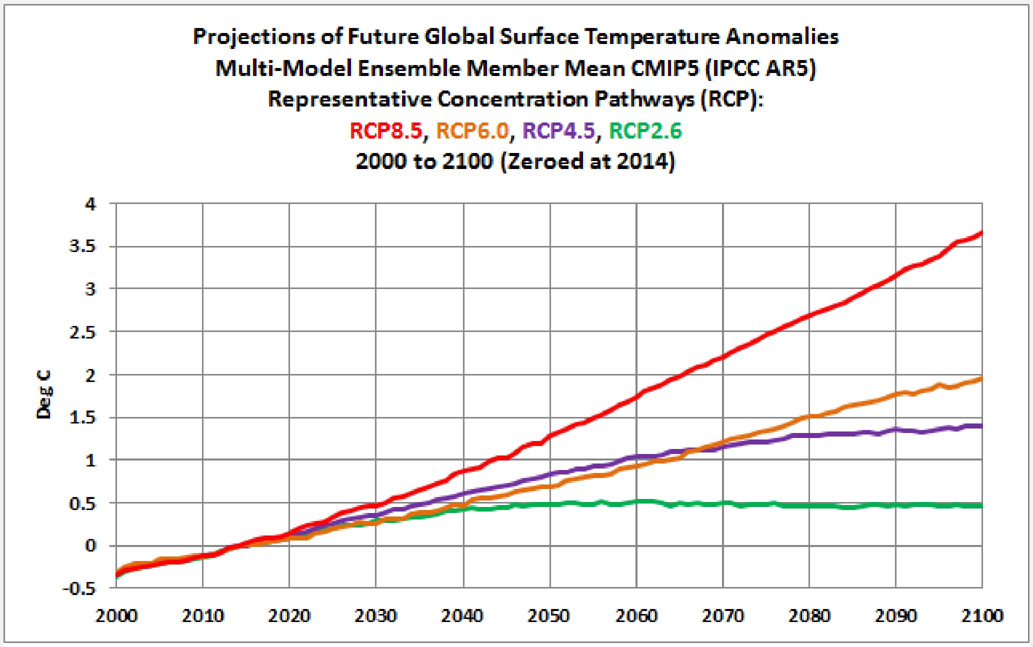


Figure 2.4-2

I've followed the same format for projections of global precipitation in Figure 2.4-3, for the 4 RCP scenarios, based on the models stored in the CMIP5 archive. Like global surface temperatures, the projected increases in global precipitation also depend on the projections of greenhouse gas emissions.

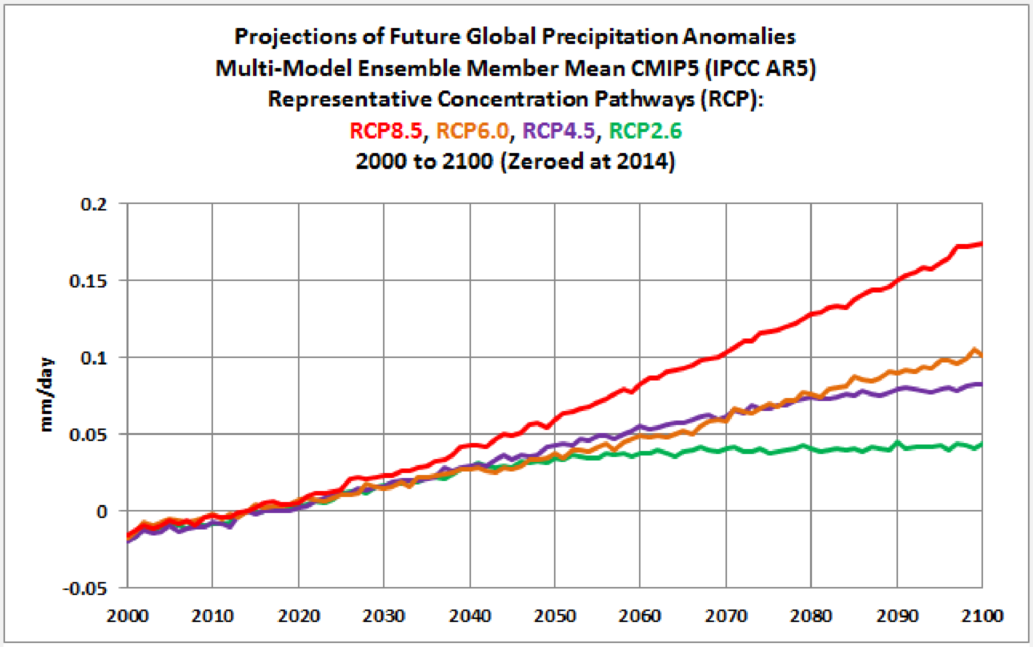


Figure 2.4-3

# # #

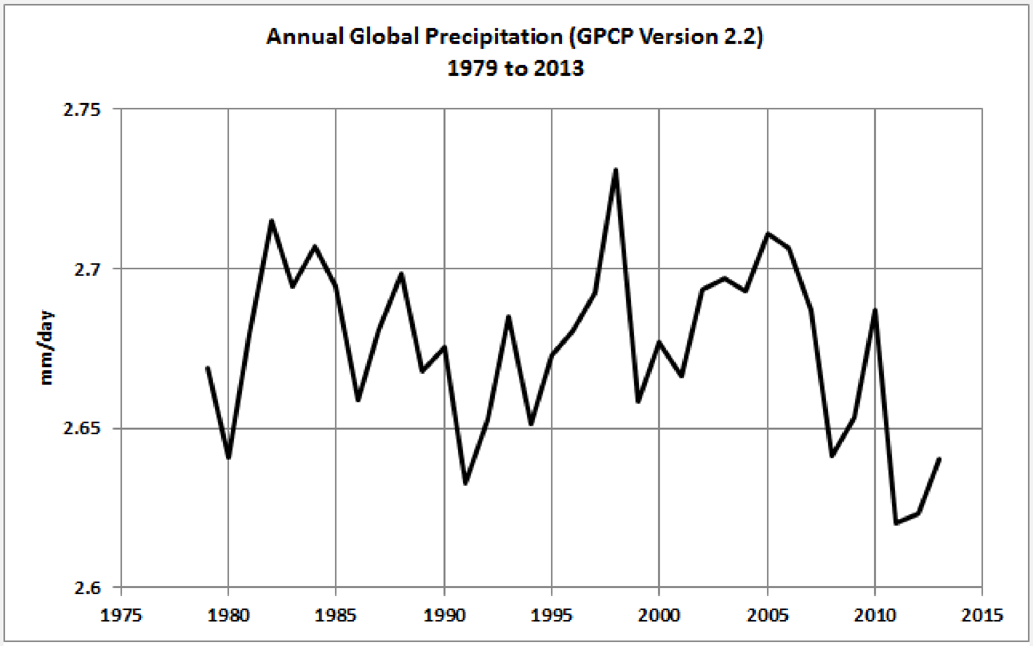


Figure 2.4-4

With RCP 8.5, the average of the climate model projections shows an increase of approximately 0.175 mm/day (about 0.007 inches/day) in global precipitation. Because most people don't have a feel for the present global precipitation rate, I've provided a graph of the observed global precipitation, based on the GCPC Version 2.2 satellite- and rain gage-based dataset, in Figure 2.4-4. The observed average global precipitation for the past 35 years is in the neighborhood of 2.65 to 2.7 mm/day (about 0.1 inches/day), so the RCP 8.5 projection is showing about a 7% increase in global precipitation by 2100.

You'll note a curiosity in Figure 2.4-4. According to the data, global precipitation has decreased over the past 35 years, not increased. We compared global precipitation data to simulations of global precipitation in the Introduction and in a future chapter. You should not be surprised to discover that climate models do not properly simulate global precipitation.

IS THE WORST-CASE SCENARIO PLAUSIBLE?

Many people consider RCP8.5 to be the business-as-usual scenario…what will happen if mankind does not change its evil habits. But is it realistic?

"It is a world that is very, very implausible", according to Matt Ridley.

Matt Ridley is described by Wikipedia as:

> *…a British journalist who has written several popular science books. He is also a businessman and a Conservative member of the House of Lords.*

Matt Ridley publishes articles at his blog RationalOptimist.com and at the *Financial Post*. He wrote an article in June 2014 about the latest IPCC scenarios, focusing much of it on the worst-case RCP8.5. See his post More growth, less warming, which was cross posted at FinancialPost as Junk Science Week: IPCC commissioned models to see if global warming would reach dangerous levels this century. Consensus is 'no'. Ridley writes:

> *But what about the fourth scenario? This is known as RCP8.5, and it produces 3.5 degrees of warming in 2081-2100 [or 4.3 degrees above pre-industrial levels]. Curious to know what assumptions lay behind this model, I decided to look up the original paper describing the creation of this scenario. Frankly, I was gobsmacked. It is a world that is very, very implausible.*
>
> *For a start, this is a world of "continuously increasing global population" so that there are 12 billion on the planet. This is more than a billion more than the United Nations expects, and flies in the face of the fact that the world population growth rate has been falling for 50 years and is on course to reach zero – i.e., stable population – in around 2070. More people mean more emissions.*
>
> *Second, the world is assumed in the RCP8.5 scenario to be burning an astonishing 10 times as much coal as today, producing 50% of its primary energy from coal, compared with about 30% today. Indeed, because oil is assumed to*

> *have become scarce, a lot of liquid fuel would then be derived from coal. Nuclear and renewable technologies contribute little, because of a "slow pace of innovation" and hence "fossil fuel technologies continue to dominate the primary energy portfolio over the entire time horizon of the RCP8.5 scenario." Energy efficiency has improved very little.*
>
> *These are highly unlikely assumptions. With abundant natural gas displacing coal on a huge scale in the United States today, with the price of solar power plummeting, with nuclear power experiencing a revival, with gigantic methane-hydrate gas resources being discovered on the seabed, with energy efficiency rocketing upwards, and with population growth rates continuing to fall fast in virtually every country in the world, the one thing we can say about RCP8.5 is that it is very, very implausible.*
>
> *Notice, however, that even so, it is not a world of catastrophic pain. The per capita income of the average human being in 2100 is three times what it is now. Poverty would be history. So it's hardly Armageddon.*

The rest of Matt Ridley's article is as enlightening. Here's another link.

CHAPTER CLOSING

Climate model-based projections of future worst-case climate scenarios are based on an extremely unlikely future Earth, but it also has to be kept in mind that they are based on simulations of a planet that bears no relationship to Earth.

Keeping in mind that the climate forcings associated with the RCP emission scenarios are used to drive the climate models used by the IPCC, were you aware of the following?

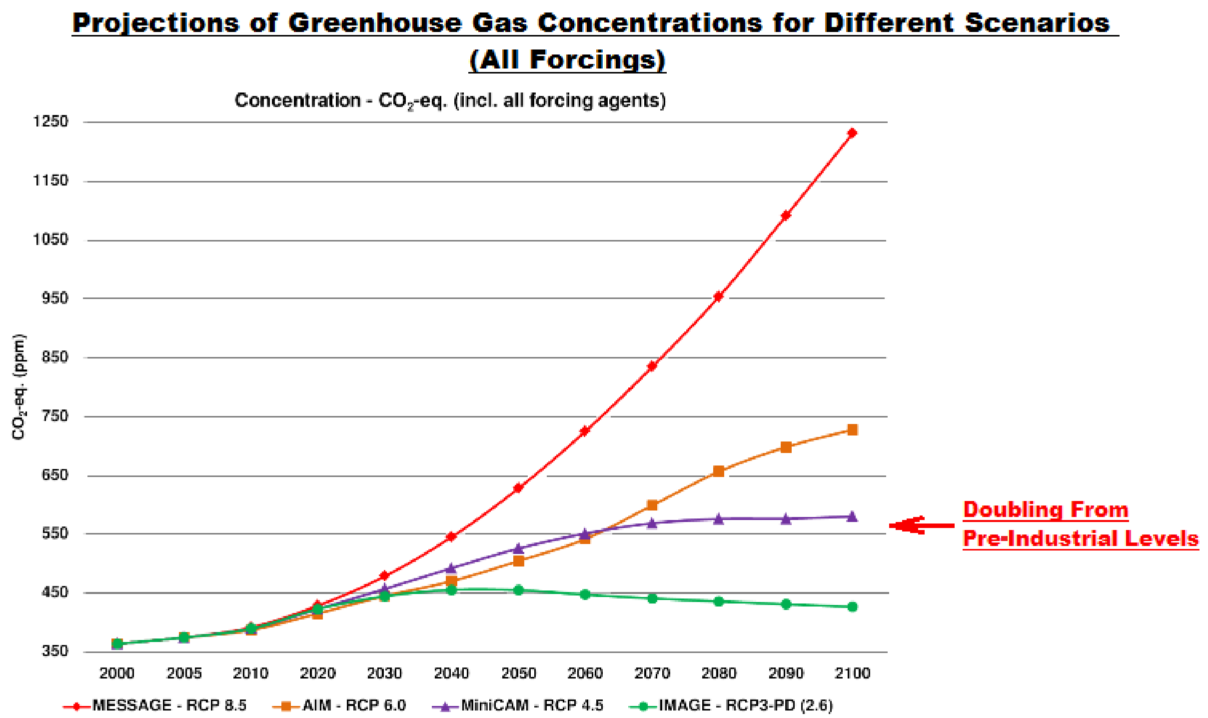
- The RCP emission scenarios are "not policy prescriptive". That is, the RCP emission scenarios are not intended to serve as recommendations or references for climate-related policies.
- The RCP emission scenarios "do not represent specific futures with respect to climate policy action (or no action)…"
- "The differences between the RCPs can therefore not directly be interpreted as a result of climate policy or particular socioeconomic developments."

Yet policies are being based on the outputs of the climate models (which aren't simulating Earth's climate as it existed in the past, exists now, or might exist in the future) that rely on those emission scenarios for inputs.

2.5 – What is Climate Sensitivity?

Climate sensitivity is a metric used by climate scientists/modelers to express the change in global temperature in response to the increase in anthropogenic carbon dioxide. Because it is an attempt to quantify how global surface temperatures respond to increased emissions of man-made carbon dioxide, climate sensitivity is a very important metric in discussions of global warming and climate change, yet according to the IPCC's most recent report, there still can be no "best estimate" of climate sensitivity.

Climate sensitivity is expressed as the change in global temperature from preindustrial times that would result if or when the concentrations of carbon dioxide in the atmosphere double from preindustrial levels—usually considered to be about 280 ppmv (parts per million by volume).



Source of Original:
http://en.wikipedia.org/wiki/File:All_forcing_agents_CO2_equivalent_concentration.png

Figure 2.5-1

That raises the question: when could we expect to double the concentrations of carbon dioxide in the atmosphere? Because there are other man-made greenhouse gases to consider, scientists look at the projections of all of them for specific scenarios and convert all of the greenhouse gases into equivalent values in terms of carbon dioxide, then add them all together. The combination of all of the greenhouse gases in that way is called the CO_2-equivalent for all man-made greenhouse gases.

Figure 2.5-1 above presents the expected growth rates in the "CO_2-equivalent" for all forcings, using the scenarios from the IPCC's 5th Assessment Report. The graph is available through Wikipedia here. If we follow the curve of worst-case RCP8.5 scenario, the CO_2-equivalent might be expected to double (reach 560 ppmv) by around 2040, about 2.5 decades from now. With the two mid-range scenarios, the doubling might be in about 50 years, around 2065. Keep in mind, though, that the range of temperatures given for climate sensitivity is related to pre-industrial temperatures, not today's global temperatures.

Before we move on to the next logical question, there are two types of climate sensitivity:

- Transient Climate Response (TCR), and
- Equilibrium Climate Sensitivity (ECS).

Transient Climate Response (TCR) is defined as the change in temperature (from pre-industrial values, not current temperatures) we might expect when the CO_2-equivalent doubles from its pre-industrial concentration, if the concentrations increased at 1% per year. Phrased differently, Transient Climate Response (TCR) is the expected change in temperature at the point in time when the concentrations of carbon dioxide have doubled from their pre-industrial levels.

Equilibrium Climate Sensitivity (ECS) is the total change in temperature (from pre-industrial values, not current temperatures) we might expect after the CO_2-equivalent doubles from its pre-industrial concentration and we wait for the climate to reach a new state of equilibrium. Recall that the oceans have a very high capacity to store heat. The oceans are also believed to warm at a rate that's slower than the rate at which the man-made greenhouse effect is increasing. Therefore, it would take some time after the doubling of CO_2 for the entire warming to be realized. Equilibrium climate sensitivity is, thus, the expected change in temperature when the whole climate system reaches a new state of equilibrium, after the concentrations of carbon dioxide double from their pre-industrial levels.

Australia's Department of the Environment has a reasonably non-technical discussion of climate sensitivity in their Climate Sensitivity Fact Sheet (.pdf). At the bottom, it also includes an illustration that shows the broad estimated range of equilibrium climate sensitivities. Like many climate change metrics, due to a multitude of unknowns, there is no specific value assigned to climate sensitivity. Instead, climate scientists provide a likely range that's very broad. Depending on the study and the metrics used to calculate it, equilibrium climate sensitivity (ECS) might be as low as a 1 deg C (or less) for the doubling or as high as 9 deg C…though we might have expected a lot more warming to this point if the climate sensitivity was as high as 9 deg C. In their recent 5th Assessment Report, the IPCC has limited the "likely" range of equilibrium climate sensitivity to 1.5 deg C to 4.5 deg C for a doubling of CO_2. And they further qualify it as extremely unlikely to be less than 1 deg C or more than 6 deg C.

A HISTORY OF CLIMATE SENSITIVITY ESTIMATES

Sellers (1974) A Reassessment of the Effects of CO_2 Variations on a Simple Global Climatic Model established a not-very-alarming climate sensitivity that ranged from 0.6 deg C to 2.4 deg C for a doubling of CO_2. See his Table 2.

That must not have been high enough, so in 1979, the National Academy of Sciences produced a report titled Carbon Dioxide and Climate: A Scientific Assessment. It is also known as *The Charney Report*. In Chapter 1, Summary and Conclusions, they wrote:

> *We estimate the most probable warming for a doubling of CO_2 to be near 3 deg C with a probable error of +/- 1.5 deg C.*

"3 deg C with a probable error of +/- 1.5 deg C" equates to the IPCC's current range of 1.5 deg C to 4.5 deg C for equilibrium climate sensitivity, and the latest IPCC report trailed the 1979 NAS study (Charney Report) by 34 years. And between those two reports, estimates of equilibrium climate sensitivity have varied very little. In other words, the Charney Report established the climate sensitivity that appears to be the programming goal of climate modelers from that time forward.

The IPCC's first report is dated 1991. The equilibrium climate sensitivity in the IPCC's 1st Assessment Report (FAR) (29MB .pdf) was listed as (my boldface):

> *The long term change in surface air temperature following a doubling of carbon dioxide (referred to as the climate sensitivity) is generally used as a benchmark to compare models. The range of results from model studies is 1.9 to 5.2°C. Most results are close to 4.0°C but recent studies using a more detailed but not necessarily more accurate representation of cloud processes give results in the lower half of this range.* ***Hence the models results do not justify altering the previously accepted range of 1.5 to 4.5°C****.*

There were similar results in 1995 from the 2nd Assessment Report (SAR) (51 MB .pdf) (my boldface):

> *D.2 Climate model feedbacks and uncertainties*
>
> *Warming from radiative forcing will be modified by climate feedbacks which may either amplify (a positive feedback) or reduce (a negative feedback) the initial*

> *response.* ***The likely equilibrium response of global surface temperature to a doubling of equivalent carbon dioxide concentration (the "climate sensitivity") was estimated in 1990 to be in the range 1.5 to 4.5 °C, with a "best estimate" of 2.5°C.*** *The range of the estimate arises from uncertainties in the climate models and in their internal feedbacks, particularly those concerning clouds and related processes.* ***No strong reasons have emerged to change these estimates of the climate sensitivity.***

And the results were about the same in the 3rd Assessment Report (TAR) in 2001. See page 67 of the TAR Technical Summary of the Working Group I Report (3MB). They write, where AOGCM stands for Atmosphere-Ocean General Circulation Models (my boldface):

> *AOGCM results*
>
> **Climate sensitivity is likely to be in the range of 1.5 to 4.5°C.** This estimate is unchanged from the first IPCC Assessment Report in 1990 and the SAR. *The climate sensitivity is the equilibrium response of global surface temperature to a doubling of equivalent CO_2 concentration.* ***The range of estimates arises from uncertainties in the climate models and their internal feedbacks, particularly those related to clouds and related processes****.*

The IPCC's 4th Assessment Report (AR4) in 2007 includes slightly different results. See the IPCC's Climate sensitivity and feedbacks webpage for AR4. There they write (My boldface):

> *The equilibrium climate sensitivity is a measure of the climate system response to sustained radiative forcing. It is defined as the equilibrium global average surface warming following a doubling of CO_2 concentration.* ***Progress since the TAR enables an assessment that climate sensitivity is*** **likely** ***to be in the range of 2 to 4.5°C with a best estimate of about 3°C,*** *and is* very unlikely *to be less than 1.5°C. Values substantially higher than 4.5°C cannot be excluded, but agreement of models with observations is not as good for those values.*

The IPCC confirmed in the next paragraph of 2007's AR4 that clouds are the greatest source of uncertainty (my boldface):

> *Feedbacks can amplify or dampen the response to a given forcing. Direct emission of water vapour (a greenhouse gas) by human activities makes a negligible contribution to radiative forcing. However, as global average temperature increases, tropospheric water vapour concentrations increase and this represents a key positive feedback but not a forcing of climate change.* ***Water vapour changes represent the largest feedback affecting equilibrium***

> ***climate sensitivity and are now better understood than in the TAR. Cloud feedbacks remain the largest source of uncertainty.***

And in 2013's 5th Assessment Report (AR5) the IPCC still shows the same basic results, basing it on a number of different metrics. See the IPCC's AR5 Technical Summary for Working Group I (18MB .pdf). There, in Chapter TFE.6 Climate Sensitivity and Feedbacks, they write:

> *Newer studies of constraints on ECS are based on the observed warming since pre-industrial, analysed using simple and intermediate complexity models, improved statistical methods and several different and newer data sets.* ***Together with paleoclimate constraints but without considering the CMIP based evidence these studies show ECS is*** **likely** ***between 1.5°C to 4.5°C (*****medium confidence*****) and*** **extremely unlikely** ***less than 1.0°C.***

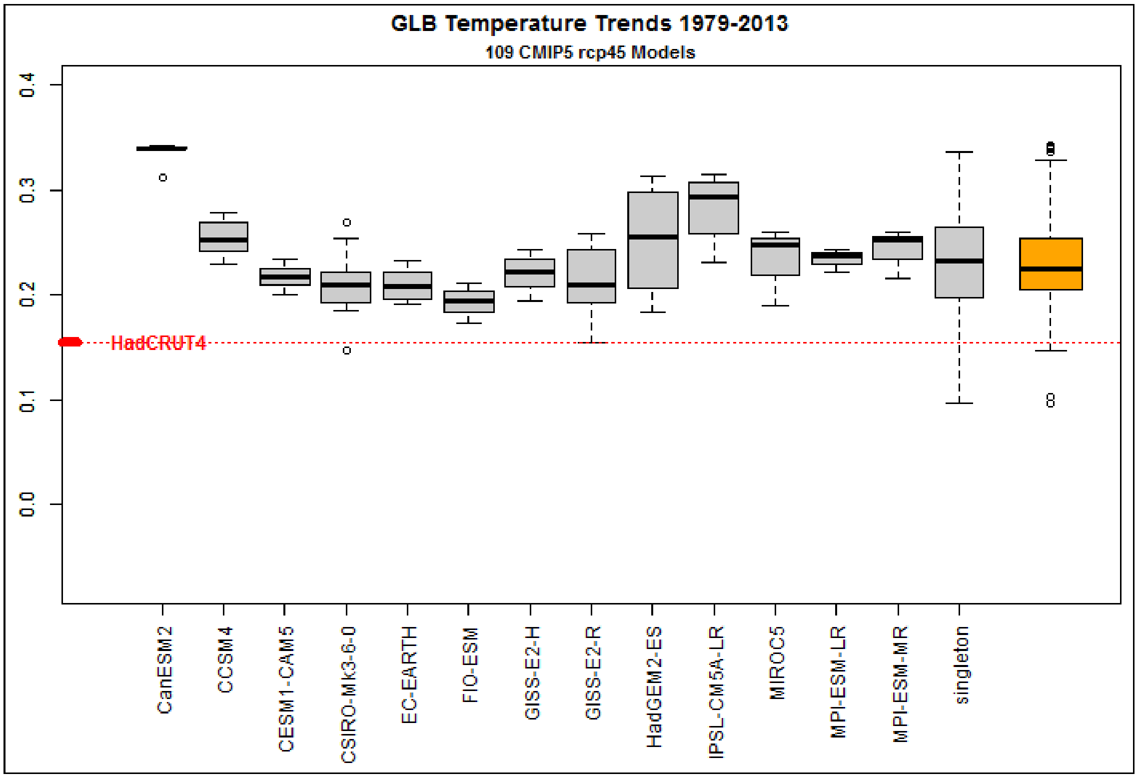
Some persons may look at the relatively constant range for equilibrium climate sensitivity (from the National Academy of Sciences report in 1979 to the most recent IPCC Assessment Report in 2013) as a form of consistency, with the current estimates verifying the early estimates. Other persons view it as stagnation, inasmuch as the climate science community, with billions of research dollars expended annually, have gained little to no additional understanding of positive and negative feedbacks (water vapor and clouds), thus the consistent wide range of estimates for equilibrium climate sensitivity. The climate science community has expended tens of billions of dollars increasing the resolution of climate models and publishing their findings…without comprehending a basic fundamental feedback. For those people, that expenditure by the climate science community doesn't make a whole lot of sense.

METHODS USED TO CALCULATE CLIMATE SENSITIVITY

There are a number of ways to calculate climate sensitivity. Climate models have been used to determine it. Unfortunately, climate models overestimate the warming we've experienced since the 1970s, and they overestimate it by a wide margin. This was presented very well in a "box and whiskers diagram" created by Steve McIntyre of ClimateAudit. McIntyre was primary force behind the independent audit of proxies and statistical methods used in the Mann et al. (1999) paper Northern Hemisphere Temperatures During the Past Millennium: Inferences, Uncertainties, and Limitations. Mann et al. (1999) was the basis for the now-infamous hockey-stick graph, which played a prominent role in the IPCC's 3rd Assessment Report (TAR). (See Figure 1 on page 3 of the TAR Summary for Policymakers.) That audit of Mann et al. (1999) resulted in the paper McIntyre and McKitrick (2005) Hockey sticks, principal components, and spurious significance.

Back to modeled versus observed warming: McIntyre's model-data box and whiskers diagram is presented as my Figure 2.5-2. It shows the modeled and observed warming rates of global surface temperatures for the period of 1973 to 2013. It is from the ClimateAudit blog post Two Minutes to Midnight, which contained an independent audit of the climate models used in the IPCC's recent 5th Assessment Report. The vertical axis (y-axis) is the trends in degrees C/decade, while the horizontal axis (x-axis) lists the climate models represented by the boxes and whiskers. The red horizontal line is the observed trend as determined by HADCRUT4 global land plus ocean surface temperature data. You'll note that nearly all of the models overestimated the warming since the end of the 1970s.

Modeled and Observed Global Surface Temperature Trends (1979-2013) by Steve McIntyre



Source: http://climateaudit.org/2013/09/24/two-minutes-to-midnight/

Figure 2.5-2

The caption for the illustration reads:

> *Boxplot of GLB temperature (tas) trends (1979-2013) from 109 CMIP5 RCP4.5 model runs versus HadCRUt4.*

And McIntyre's discussion of the illustration reads:

> *The following graph compares models to observations over the period 1979-2013, long enough to place the 1998 El Nino in the middle, but excluding the*

> *earlier hiatus of the 1950s and 1960s. 1979 is also when the satellite record commences. The figure is a standard box-and-whiskers diagram of a type routinely used in statistics (rather than some ad hoc method). I've shown models with multiple runs as separate boxes and grouped models with singleton runs together. On the right in orange, I've done a separate box-and-whisker plot for all models. (Lucia has recently done plots in a similar style: her results look similar, but I haven't parsed them yet as I've been working on this post.)*
>
> *The figure shows that nearly every run of every model ran too hot over the 1979-2013 period, with many models running substantially too hot. The discrepancy can be seen with box-and-whiskers of the ensemble, but it pervades all models.*

McIntyre concludes that portion of his blog post:

> *The boxplot shows fundamental discrepancies that pervade all models. Nor do these inconsistencies have anything to do with 15-year trends or the 1998 El Nino. IPCC's entire discussion of 15-year trends is completely worthless.*

It's safe to say, because climate models overestimate the observed warming by such a large margin, they would have little value in attempts to estimate climate sensitivity.

There is another method called "climatological constraints" which is a specialized type of climate model study. It is plagued by the known unknowns and the unknown unknowns inherent in climate models.

There are a couple of other ways that climate scientists employ to try to estimate climate sensitivity, but these are methods even the IPCC are wary of, suggesting that we exercise caution when relying on them. (1) Studies of Paleoclimatological proxies are one way. Paleoclimatology is the study of data derived from things like tree rings, corals, ice cores, and ocean or lake sediments. See the NOAA Paleoclimatology data webpage for further information and numerous examples of studies. (2) The study of the responses of global surface temperatures to naturally occurring yet drastic changes in climate forcings, like volcanoes, is another way the climate sensitivity has been calculated.

Unfortunately, the IPCC isn't very enthusiastic about those methods. In Chapter 12 of their 5th Assessment Report Long-term Climate Change: Projections, Commitments and Irreversibility (37MB) the IPCC notes:

> *Equilibrium climate sensitivity undoubtedly remains a key quantity, useful to relate a change in GHGs or other forcings to a global temperature change. But the above caveats imply that estimates based on past climate states very different from today, estimates based on time scales different than those relevant*

> *for climate stabilization (e.g., estimates based on climate response to volcanic eruptions), or based on forcings other than GHGs (e.g., spatially non-uniform land cover changes, volcanic eruptions or solar forcing) may differ from the climate sensitivity measuring the climate feedbacks of the Earth system today, and this measure, in turn, may be slightly different from the sensitivity of the Earth in a much warmer state on time scales of millennia.*

That leaves the global surface temperature data, over multidecadal timeframes, as the only realistic method that can be used to determine climate sensitivity. But that is also problematic, because it can assume that only man-made greenhouse gases are responsible for the warming…when, in reality, surface temperature and ocean heat content data indicate that naturally occurring, sunlight-fueled, coupled ocean-atmosphere processes caused much, if not all, of the warming of the oceans over the past 3+ decades.

LOW CLOUDS ARE THE DOMINANT CAUSE OF THE WIDE RANGE OF CLIMATE SENSITIVITIES IN CLIMATE MODELS

Clouds and the uncertainties behind them are mentioned numerous times in this chapter as being unknowns that cause the wide range in climate sensitivity. Early in 2015, there was a workshop for climate scientists about climate sensitivity, which was held by the Max Planck Institute at Schloss Ringberg. Gavin Schmidt, the Director of the NASA's Goddard Institute of Space Studies (GISS), was one of the attendees. Dr. Schmidt provided a brief overview of the workshop in his blog post Reflections on Ringberg at RealClimate. There, he writes:

> *The cloud feedback discussion was extremely interesting since there are a multitude of different theorised effects depending on which clouds are being discussed (Mark Zelinka and Graeme Stevens did a great job in particular in explaining these effects). The variation in climate sensitivity in models seems to be dominated by the simulations of low clouds (which are a net cooling to the climate) which have a tendency to disappear as the climate warms. Whether this can be independently constrained in the observations is unclear.*

So, according to climate models, low clouds have a cooling effect on global surface temperatures and they also tend to disappear in the models as the globe warms, reducing the cooling effect. That, of course, is a positive feedback we discussed in Chapters 1.7 and 1.8.

Dr. Schmidt's use of the word *constrained* in the last sentence in that quote is curious. If we assume he means confirm or verify, then the sentence suggests that climate scientists are unable to confirm if low clouds amounts have declined in recent decades. But there are datasets that do show a decline, so the sentence could also mean that there is no way to determine if a measured decline in low cloud cover was a response to increased emissions of greenhouse gases or was a response to naturally variability.

WHY IS THERE NO BEST ESTIMATE OF EQUILIBRIUM CLIMATE SENSITIVITY AFTER DECADES OF RESEARCH?

A very simple footnote in the IPCC Summary for Policymakers of their 5th Assessment Report explains why a best estimate of equilibrium climate sensitivity does not exist. It's their footnote 16, on the bottom of page 14 of that Summary for Policymakers. It reads (my boldface):

> [16] *No best estimate for equilibrium climate sensitivity can now be given* ***because of a lack of agreement*** *on values across assessed lines of evidence and studies.*

Isn't that odd? For years we've been told the science behind global warming and climate change is "settled science", yet, with respect to one of the most important aspects of climate science—climate sensitivity—the climate science community cannot provide a best estimate of climate sensitivity because of a "of a lack of agreement on values across assessed lines of evidence and studies." It sure does not sound as though the science is settled in any way, shape or form…after decades of research.

CHAPTER CLOSING

Were you aware that the climate science community cannot provide a best estimate of climate sensitivity because of a "of a lack of agreement on values across assessed lines of evidence and studies"?

2.6 – What are Parameterizations?

As you'll recall from Chapter 2-1, climate models divide the atmosphere and oceans into grids and levels. The grid sizes have gotten much smaller with the newer generations of models and there have been increases in the numbers of levels vertically. Unfortunately, the grid sizes are still much larger than many physical processes taking place in the oceans and atmosphere. In the oceans, these include eddies and vertical mixing, and in the atmosphere, they include convection, clouds and turbulence. (Convection is basically the transfer of heat from one place to another through the movement of heated air in the atmosphere. It is generally used in discussions of the upward and downward motion of air.) For example, thunderstorms take place at scales that are smaller than the resolution of climate models. The other problem is the computing requirements of many of these factors. The computers would be overwhelmed if they were to try to simulate every facet of these processes. So the modelers insert simplified equations called parameterizations or parameters to represent these critical processes.

For additional introductory discussions of parameterizations, see the following webpages:

- Wikipedia's Parameterization (atmospheric modeling)
- RealClimate's FAQ on Climate Models: Part II
- World Meteorological Organization's Climate Models

Maybe it's easier to think of parameterizations by the term used by engineers: fudge factors. I've also seen parameterizations described as fake physics.

MODEL DEFICIENCIES

Let's return to the testimony of Dr. Raymond W. Schmitt of the Woods Hole Oceanographic Institution, when he appeared before the U.S. Senate Committee on Commerce, Science and Transportation back in 2000. Again, Dr. Schmitt was asking the Senate to help fund the ARGO program. See the WHOI webpage titled The Ocean's Role in Climate. Dr. Schmitt writes (my boldface):

> ***Model Deficiencies***
> *In fact, oceanographers have many complaints about how poorly climate models simulate the ocean. Because of computer limitations, they must treat it as a very viscous fluid, more like lava or concrete than water. Such models fail to simulate the real ocean's changes in deep temperatures.* ***We know that the "sub-grid-scale" parameterizations for mixing processes are incorrect, reflecting none of the observed spatial variations or differences between heat and***

> ***salt.*** *This mixing drives the interior flows in the ocean. We know that the processes by which ocean currents give up their momentum are incorrectly treated. And these are not problems that will quickly yield to increased spatial and temporal resolution in the computer models. Even if computer power continues to increase by an order of magnitude every 6 years, it will be over 160 years (1) before models have the resolution necessary to simulate the smallest ocean mixing processes! Society cannot afford to wait that long. We will not come to an understanding of climate by more computational cycles of models with incorrect physics. We require a systematic study of the sub-grid-scale processes in the ocean. This is noticeably lacking in our current Global Change Research Program.*

Dr. Schmitt's note (1) reads:

> *It will take a factor of 10^8 improvement in 2 horizontal dimensions (100 km to 1 mm, the salt dissipation scale), a factor of 10^6 in the vertical dimension (~10 levels to 10^7) and ~10^5 in time (fraction of a day to fraction of a second); an overall need for an increase in computational power of ~10^{27}. With an order of magnitude increase in computer speed every 6 years, it will take 162 years to get adequate resolution in computer models of the ocean.*

In other words, computers may have enough power in 1½ Centuries to run still-unwritten programs that may (or may not) properly simulate ocean processes. And that's about the time required to assemble enough subsurface temperature and salinity data so that the oceanographers will have something they can use to validate the models. What we have now is speculation—nothing more and nothing less—just speculation about ocean processes.

PARAMETERS AS TUNING KNOBS

We'll discuss climate model tuning in the next chapter, but I wanted to include in this chapter a portion of the abstract of a paper that will serve as the first reference there. That paper is Mauritsen, et al. (2012) [Tuning the Climate of a Global Model] [paywalled]. A preprint edition is [here]. The abstract includes, with respect to climate model tuning:

> *The tuning is typically performed by adjusting uncertain, or even non-observable, parameters related to processes not explicitly represented at the model grid resolution. The practice of climate model tuning has seen an increasing level of attention because key model properties, such as climate sensitivity, have been shown to depend on frequently used tuning parameters.*

CHAPTER SUMMARY

Parameterizations are approximations in climate models of known and unknown aspects of the Earth's climate, basically fudge factors. Parameterizations are used for parts of the modeled climate system where specific processes occur at scales that are smaller than the model grids and where including those processes would consume too much processing time. Climate models are tuned using these parameterizations (approximations).

2.7 – Climate Model Tuning

The tuning of climate models was briefly mentioned a few times so far in this section. In very basic terms, climate model tuning is the way in which climate modelers attempt to compensate for the known and unknown errors contained within those numerical representations of climate by adjusting parameters with known and unknown uncertainties.

Mauritsen, et al. (2012) Tuning the Climate of a Global Model [paywalled] provides a detailed overview of the tuning process. A preprint edition is here. The abstract of the paper is enlightening:

> *During a development stage global climate models have their properties adjusted or* tuned *in various ways to best match the known state of the Earth's climate system. These desired properties are observables, such as the radiation balance at the top of the atmosphere, the global mean temperature, sea ice, clouds and wind fields. The tuning is typically performed by adjusting uncertain, or even non-observable, parameters related to processes not explicitly represented at the model grid resolution. The practice of climate model tuning has seen an increasing level of attention because key model properties, such as climate sensitivity, have been shown to depend on frequently used tuning parameters. Here we provide insights into how climate model tuning is practically done in the case of closing the radiation balance and adjusting the global mean temperature for the Max Planck Institute Earth System Model (MPI-ESM). We demonstrate that considerable ambiguity exists in the choice of parameters, and present and compare three alternatively tuned, yet plausible configurations of the climate model. The impacts of parameter tuning on climate sensitivity was less than anticipated.*

Rephrasing the first two sentences, Mauritsen et al. (2012) are basically saying that climate models are tuned in an effort to try to match the models to observations-based data. But global surface temperature data and wind fields are spatially incomplete even during their tuning period of 1976 to 2005. Cloud cover data, even satellite-based data, are problem riddled. Satellite-based sea ice data are in a much better state. That leaves the radiative imbalance at the top of the atmosphere.

As we discussed in Chapter 1-10, satellites were put in place to measure the radiative imbalance at the top of the atmosphere, but the measured imbalance was considered to be too great to be realistic, so they initially adjusted the radiative imbalance to what was simulated by models. Radiative imbalance is also calculated from ocean heat uptake, and as we'll discuss and illustrate later, that ocean heat content data have to be adjusted to show warming during the ARGO era. Bottom line: climate models are tuned to data that have their own problems and great inherent uncertainties.

The next sentence is also noteworthy:

> *The tuning is typically performed by adjusting uncertain, or even non-observable, parameters related to processes not explicitly represented at the model grid resolution.*

As discussed in the preceding chapter on parameterizations, there are processes within the oceans and atmosphere that are poorly understood or that cannot be modeled because the grid sizes of the models are far too large. So Mauritsen et al. (2012) are saying that they adjust the factors within the equations that represent those unknown and uncertain processes, and processes that can't be modeled, in order to tune the models to data that have their own inherent uncertainties.

Within the body of the paper, Mauritsen et al. (2012) describe the "frequently used tuning parameters". They write in the draft:

> *…the radiation balance is controlled primarily by tuning cloud-related parameters at most climate modeling centers [e.g. Watanabe et al., 2010; Donner et al., 2011; Gent et al., 2011; The HadGEM2 Development Team, 2011; Hazeleger et al., 2011], while others adjust the ocean surface albedo [Hourdin et al., 2012] or scale the natural aerosol climatology to achieve radiation balance [Voldoire et al., 2012].*

It's interesting that climate modeling groups adjust different parameters to control the radiation balance within the models. Some use very uncertain cloud properties, and based on the number of cited references, that appears to be the method used often. Some control the radiative balance at the top of the atmosphere by adjusting the reflecting properties of the ocean surfaces (the "ocean surface albedo"). While as discussed in Voldoire et al., 2012 The CNRM-CM5.1 global climate model: description and basic evaluation others adjust the timings, locations, etc., of numerous types of naturally occurring aerosols to achieve the desired model performance:

> *Five tropospheric aerosol types are used: sulphate, organic, black carbon, sea salt and sand dust. Volcanic aerosols can also be specified as a stratospheric aerosol type.*

Basically, there is no consensus (groupthink) for how climate models should be tuned.

Mauritsen et al. (2012) then discuss the pros and cons of using cloud parameters as a tuning means.

> *Tuning cloud parameters partly masks the deficiencies in the simulated climate, as there is considerable uncertainty in the representation of cloud processes. But just like adding flux-corrections, adjusting cloud parameters involves a process of error compensation, as it is well appreciated that climate models poorly represent clouds and convective processes. Tuning aims at balancing the Earth's energy budget by adjusting a deficient representation of clouds, without necessarily aiming at improving the latter.*

Of course, it's likely there are other poorly modeled processes and yet even more factors with great uncertainties the modelers are trying to compensate for by adjusting parameterizations of clouds, ocean surface albedo and aerosols.

Mauritsen et al. (2012) then go on to describe their process for tuning the climate model:

> *2.1. The tuning process*
>
> *We tune the radiation balance with the main target to control the pre-industrial global mean temperature by balancing the TOA net longwave flux via the greenhouse effect and the TOA net shortwave flux via the albedo affect.*

In other words, for the pre-industrial periods within the models (the period before man-made greenhouse gases started to rise), they set the global surface temperatures by balancing the sunlight entering and leaving the top of the atmosphere and the longwave (infrared) radiation entering and leaving the top of the atmosphere.

Mauritsen et al. (2012) continued describing a three-step process:

> *The methodology of tuning the radiation balance may vary between model development groups, and is usually adapted to the specific goals and constraints of the exercise. After a problem has been identified in the coupled climate model, we iterate the following steps until a satisfactory solution is found:*
>
> *1. Short runs of single months, or if possible one or more years, with prescribed observed SST's and sea ice concentration; first with reference parameter settings, and then altered parameter settings.*

In this step, they are forcing the models with sea surface temperatures and sea ice concentrations, and then checking the model (atmospheric) response for short time periods. And then they use sea surface temperatures for the period of 1976-2005 for the next multidecadal phase:

> *2. A longer simulation with altered parameter settings obtained in step 1 and observed SST's, currently 1976-2005 from the Atmospheric Model Intercomparison Project (AMIP), is compared with the observed climate.*

Then, after they make those adjustments, they move onto step 3:

> *3. Implement the changes in the coupled model setup to run under pre-industrial conditions and evaluate the altered climate. Frequently, we make small parameter changes in this step to fine-tune the climate, without first revisiting steps 1 and 2.*

The closing discussion of Mauritsen et al. (2012) begins (my boldface):

> *Parameter tuning is the last step in the climate model development cycle, and invariably involves making sequences of choices that influence the behavior of the model. Some of the behavioral changes are desirable, and even targeted, but others may be a side effect of the tuning.* ***The choices we make naturally depend on our preconceptions, preferences and objectives****. We choose to tune our model because the alternatives - to either drift away from the known climate state, or to introduce flux-corrections - are less attractive.*

The greatest assumptions are of course that their "preconceptions, preferences and objectives" are correct.

Chapter 9 – Evaluation of Climate Models of the IPCC's 5th Assessment Report (WG1) also refers to Mauritsen et al. (2012). See Box 9.1, where they write (my boldface and caps):

> *With very few exceptions (Mauritsen et al., 2012; Hourdin et al., 2013) modelling centres do not routinely describe in detail how they tune their models. Therefore the complete list of observational constraints toward which a particular model is tuned is generally not available. However, it is clear that tuning involves trade-offs; this keeps the number of constraints that can be used small and usually focuses on global mean measures related to budgets of energy, mass and momentum.* ***It has been shown for at least one model that the tuning process does not necessarily lead to a single, unique set of parameters for a given model, but that different combinations of parameters can yield equally plausible models (Mauritsen et al., 2012). HENCE THE NEED FOR MODEL TUNING MAY INCREASE MODEL UNCERTAINTY.***

The final sentence in that quote is important, so I'll repeat it. "…the need for model tuning may increase model uncertainty."

The boldfaced sentence before it is equally important. Basically they're saying that they can adjust numerous parameters in different ways and create models with plausible results. And as we know from the preceding quote, the tuning assumes their "preconceptions, preferences and objectives" are correct.

To sum up this portion of this chapter, I'm going to refer to a blog post Climate model tuning by Dr. Judith Curry. As you'll recall, Dr. Curry is Professor and Chair of the School of Earth and Atmospheric Sciences at the Georgia Institute of Technology. Her post "Climate model performance" discusses Mauritsen et al. (2012). She begins her post:

> *Arguably the most poorly documented aspect of climate models is how they are calibrated, or 'tuned'*

Then after presenting portions of Mauritsen et al. (2012), Dr. Curry writes:

> ***JC comment:*** *This paper is indeed a very welcome addition to the climate modeling literature. The existence of this paper highlights the failure of climate modeling groups to adequately document their tuning/calibration and to adequately confront the issues of introducing subjective bias into the models through the tuning process.*
>
> *Tuning/calibration is unavoidable in a complex nonlinear coupled modeling system. The key is to document the tuning, both the goals and actual calibration process, in the manner in which the German climate modeling group has done.*

MODELS CANNOT BE EVALUATED AGAINST THE PERIODS AND METRICS USED FOR TUNING

I saved a quote from Mauritsen et al. (2012) for this part of the discussion of climate models:

> *In addition to targeting a TOA radiation balance and a global mean temperature, model tuning might strive to address additional objectives, such as a good representation of the atmospheric circulation, tropical variability or sea-ice seasonality. But in all these cases it is usually to be expected that* ***improved performance arises not because uncertain or non-observable parameters match their intrinsic value – although this would clearly be desirable – rather that compensation among model errors is occurring****. This raises the question as to whether tuning a model influences model-behavior, and places the burden on the model developers to articulate their tuning goals, as including quantities in model evaluation that were targeted by tuning is of little value.* ***Evaluating models based on their ability to represent the TOA radiation***

> ***balance usually reflects how closely the models were tuned to that particular target, rather than the models intrinsic qualities.***

The first portion in boldface confirms my opening statement for this chapter, that climate model tuning is the way in which climate scientists attempt to compensate for the known and unknown errors contained within those numerical representations of climate by adjusting parameters with known and unknown uncertainties.

But it's the final sentence that serves as the opening for this part of the discussion. When the climate science community compares models to data for the metrics (like global surface temperatures) and the periods (like 1976-2005) used to tune the models, then the comparison does not represent the "intrinsic qualities" of the models; the comparison simply illustrates the modelers' abilities to tune their models to that metric over that time period. That should be easily understood, but it is frequently overlooked.

The IPCC understands this. They discuss it briefly in Chapter 9 – Evaluation of Climate Models of their 5th Assessment Report (Working Group 1). In Box 9.1, they write:

> *Model tuning directly influences the evaluation of climate models, as the quantities that are tuned cannot be used in model evaluation. Quantities closely related to those tuned will provide only weak tests of model performance. Nonetheless, by focusing on those quantities not generally involved in model tuning while discounting metrics clearly related to it, it is possible to gain insight into model performance. Model quality is tested most rigorously through the concurrent use of many model quantities, evaluation techniques, and performance metrics that together cover a wide range of emergent (or un-tuned) model behaviour.*

Therefore, when we see climate scientists comparing metrics like global surface temperature data to the model simulations of them, we need to know if the models were tuned to those metrics and for what periods. Unfortunately, only two of the more than twenty climate modeling groups, as the IPCC noted, have furnished that information.

At least one modeling group used the period recent warming of 1976-2005 as a reference for their tuning. And as we'll see later in this book, it appears that many (if not all) of the other groups used the same warming period as well.

CLOSING COMMENTS

Climate model tuning is process used by climate scientists to attempt to compensate for the known and unknown model errors by adjusting parameters with known and unknown uncertainties. Because climate models need to be tuned, the model outputs reflect the tuning, not the "models intrinsic qualities". That is, because climate models are tuned to mimic certain climate metrics during specific time periods, they then cannot be evaluated against those metrics at those times. Doing so simply confirms the modelers' abilities to tune the models. Unfortunately, only 2 of the 20+ modeling groups have documented how they tune their models.

2.8 – Climate Models Do Not Make Forecasts or Predictions of Future Climate

Weather models are used to make forecasts or predictions of future weather. Weather models are initialized (started) from existing weather conditions around the globe and, because they can simulate processes that can cause weather to change over a few days or weeks, weather models then simulate what weather might be like in the short-term. But climate models are not like weather models.

CLIMATE MODELS MAKE PROJECTIONS, NOT FORECASTS OR PREDICTIONS

Climate models, on the other hand, are not used to make forecasts or predictions of future climate. Climate scientists argue that climate models make projections, not forecasts or predictions of future climate. An example of such a discussion occurred in comments portion of the blog post Are regional climate models ready for prime time? at ClimateDialogue. See ClimateDialogue's About webpage where they state:

> *Climate Dialogue offers a platform for discussions between (climate) scientists on important climate topics that are of interest to both fellow scientists and the general public. The goal of the platform is to explore the full range of views that scientists have on these issues.*

There were three climate scientists invited to prepare posts for that topic, two of which would be considered as adhering to the consensus:

- Dr. Bart van den Hurk, Professor of Climate Interactions with the Socio-Ecological System, at VU University Amsterdam
- Dr. Jason Evans, Associate Professor in the Climate Change Research Centre, at the University of New South Wales

The third climate scientist would be considered a skeptic:

Dr. Roger Pielke, Sr., Senior Research Scientist, at the University of Colorado Boulder. Dr. Pielke, Sr. is also an Emeritus Professor of Atmospheric Science at Colorado State University.

Dr. Pielke, Sr. used *prediction* a number of times in his article on the Are regional climate models ready for prime time? post. Both Dr. van den Hurk and Dr. Evans took exception to the word prediction.

Dr. Evans argues in his May 14, 2013 at 1:41 pm comment (My boldface):

> *First comments on the guest blog of Roger Pielke Sr.:*
>
> *Roger presents a case for abandoning climate model projections altogether – or at least not allowing the impact/adaptation community and policy makers to see them as they will gain "an erroneous impression on their value." In my experience this is certainly the case if you talk about the simulations as predictions rather than projections –* ***the climate models are not predicting what the weather will be on the 5th of May 2051 – they are providing projections of the climate based on emission scenarios and initial conditions****. When dealing with those outside the climate science community I have certainly found the distinction to be important.*

Of the boldfaced comments, that was an odd initial statement by Dr. Evans. I'll agree we aren't interested in the weather in 2051, but we are interested in how much global surfaces are going to warm by 2051 or how high sea levels may have risen by then. However, the second portion ("…they are providing projections of the climate based on emission scenarios and initial conditions") does help to shed some light.

Dr. van den Hurk's May 14, 2013 at 1:46 pm reply to Dr. Pielke, Sr. includes what I consider to be a better explanation of the difference between a prediction and projection (My boldface):

> Roger considers projections and predictions to be synonyms, but I disagree with this, and also feel that this assumption is an important element in the controversy under discussion. **A prediction is a statement on the expected situation in the near future starting from a current state of the system, while a projection is a possible evolution of the system given an assumed (external) driver.**

That is, one reason climate models don't make forecasts or predictions is because they are not initialized from known past climate conditions. The term "possible evolution" is a very helpful description of what climate models provide, especially when combined with "…an assumed (external) driver."

The discussion of prediction versus projection continued on that thread at ClimateDialogue.

CLIMATE MODELS ARE NOT SIMULATING EARTH'S CLIMATE AS IT EXISTED IN THE PAST, EXISTS NOW, AND MIGHT EXIST IN THE FUTURE

Not only aren't climate models initialized from past known climate conditions, climate models also cannot simulate the processes that can cause climate to vary naturally over annual, decadal or multidecadal timeframes.

As a result, climate models are not expected by climate scientists to simulate when and where climate might vary in the future. This came as a tremendous surprise for many people when it was announced by one of the IPCC's lead authors of back in 2007.

I'm referring to a 2007 post at Nature.com's blog ClimateFeedback by Dr. Kevin Trenberth of the National Center for Atmospheric Research. Dr. Trenberth was lead author of the IPCC's 1995, 2001 and 2007 IPCC reports. The fact that climate models were not initialized to match any state of the past climate came to light back in Kevin Trenberth's blog post Predictions of Climate. Dr. Trenberth wrote:

> *None of the models used by IPCC are initialized to the observed state and none of the climate states in the models correspond even remotely to the current observed climate. In particular, the state of the oceans, sea ice, and soil moisture has no relationship to the observed state at any recent time in any of the IPCC models. There is neither an El Niño sequence nor any Pacific Decadal Oscillation that replicates the recent past; yet these are critical modes of variability that affect Pacific rim countries and beyond. The Atlantic Multidecadal Oscillation, that may depend on the thermohaline circulation and thus ocean currents in the Atlantic, is not set up to match today's state, but it is a critical component of the Atlantic hurricanes and it undoubtedly affects forecasts for the next decade from Brazil to Europe. Moreover, the starting climate state in several of the models may depart significantly from the real climate owing to model errors. I postulate that regional climate change is impossible to deal with properly unless the models are initialized.*

Skeptics' jaws around the globe dropped onto their keyboards with a collective crunch when that blog post was published back in 2007. That blog post is still referred to today.

Dr. Trenberth was candid with its remarks about El Niño processes and the Atlantic Multidecadal Oscillation, both of which we'll discuss in the next section. However, Dr. Trenberth was not totally open about them. Scientific papers have since disclosed that climate models do not, cannot, simulate the processes that cause El Niño and La Niña events or the Atlantic Multidecadal Oscillation. And those naturally occurring processes can contribute greatly to global warming or stop it. Yet they are not simulated properly by even the most current generation of climate models.

Dr. Trenberth was especially honest with his statement "None of the models used by IPCC are initialized to the observed state and none of the climate states in the models correspond even remotely to the current observed climate." That means none of the models are expected to be in-phase with reality. And that brings us back to the comparison to a stockbroker's models. Would you trust your money to a stockbroker whose models were not in-phase with the stock market? Of course you wouldn't.

There is another extremely enlightening portion of that quote: "…none of the climate states in the models correspond even remotely to the current observed climate. In particular, the state of the oceans, sea ice, and soil moisture has no relationship to the observed state at any recent time in any of the IPCC models." In other words, the number-crunched climates in the models used by the IPCC have no relationship to the real world. That failing is compounded by the fact that climate models cannot simulate the naturally occurring coupled ocean-atmosphere processes, like El Niño and the Atlantic Multidecadal Oscillation, processes which cause climate to vary over annual, decadal and multidecadal periods.

You'll be amazed when we get to the discussion of what climate models do not properly simulate. See Chapter 2.13, which is the last chapter in this section.

The opening two sentences in the next paragraph of Dr. Trenberth's blog post were also very important:

> *The current projection method works to the extent it does because it utilizes differences from one time to another and the main model bias and systematic errors are thereby subtracted out. This assumes linearity.*

Of course, in recent years, that projection method has been found not to work. Climate models did not anticipate the slowdown in global warming, and with every year that goes by with global warming rates far below the rates projected by that method, the models look more and more foolish.

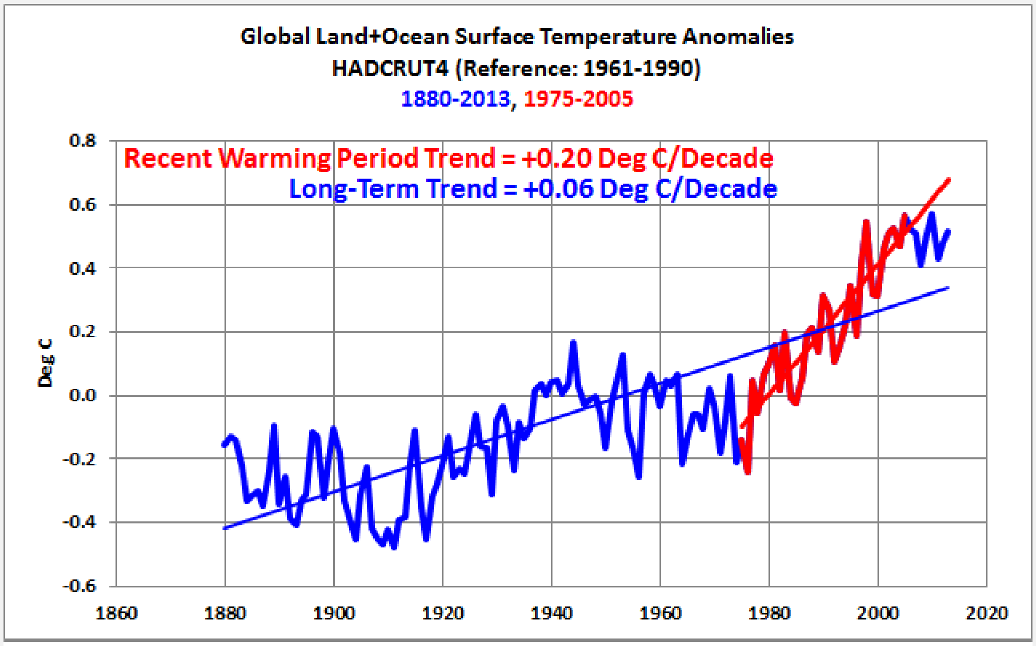
The other problem is that global warming since the late 1800s has not been linear, and will not likely be linear in the future…as the slowdown has exposed. During some (approximately) 30-year periods, global surface temperatures warm faster than the long-term trend and during the adjoining 30-year periods, global surface temperatures warm much slower than the long-term trend…and can actually cool. That's blatantly obvious in the global surface temperature record as we've illustrated numerous times in this book…and as we'll continue to show throughout it. Those multidecadal variations are hard to miss.

Scientific studies that attempt to spin the climate model failings have become more frequent in recent years. One of them was the paper was Risbey et al. (2014) Well-estimated global surface warming in climate projections selected for ENSO phase. The abstract reads (my boldface):

> The question of how climate model projections have tracked the actual evolution of global mean surface air temperature is important in establishing the credibility of their projections. Some studies and the IPCC Fifth Assessment Report suggest that the recent 15-year period (1998–2012) provides evidence that models are overestimating current temperature evolution**. Such comparisons are not evidence against model trends because they represent only one realization where the decadal natural variability component of the model climate is generally not in phase with observations.** We present a more appropriate test of models where only those models with natural variability (represented by El Niño/Southern Oscillation) largely in phase with observations are selected from multi-model ensembles for comparison with observations. These tests show that climate models have provided good estimates of 15-year trends, including for recent periods and for Pacific spatial trend patterns.

Risbey et al. (2014) have noted a major flaw with the climate models used by the IPCC for their 5th Assessment Report—that they are "generally not in phase with observations". Remarkably, they don't accept that as a flaw. If your stock broker's models were out of phase with observations, would you continue to invest with that broker based on their out-of-phase models or would you look for another stock broker whose models were in-phase with observations? Of course, you'd look elsewhere.

Unfortunately, we can't choose from other climate "broker" models. The out-of-phase climate models are the only ones available. There are no climate models that can simulate naturally occurring coupled ocean-atmosphere processes that can contribute to global warming and that can stop global warming…or, obviously, simulate those processes in-phase with the real world.



Projections of Future Global Surface Warming Are Based On A Recent Naturally Enhanced Upswing In Temperature (1975-2005), Not Long-Term Data (1880 to 2013)

Figure 2.8-1

And returning to Trenberth's statement about climate models assuming linearity, what Trenberth and the authors of Risbey et al. (2014) conveniently overlooked was that climate models were <u>not</u> tuned to the long-term <u>linear</u> trend in global warming. They align with the trend of one of the phases, Figure 2.8-1, which was a naturally enhanced upswing that started in the mid-1970s. Now that the natural processes that govern global surface temperatures appear to have changed phase, the modeled warming is being shown to be grossly overestimated.

CHAPTER SUMMARY

Climate models are not like the weather models, the results of which we see daily from our local weatherperson. Climate models are not making predictions. Climate models are showing "possible evolutions" of Earth's climate based on an "assumed (external) driver". Unfortunately, climate models are not simulating climate as it existed on Earth in the past, or as it exists now, or as it may exist in the future. Reason 1: Climate models are not initialized (started) from known past climate conditions. Reason 2: Climate models still cannot simulate known modes of natural variability that can cause climate to change over annual, decadal and multidecadal timeframes.

2.9 – Can the IPCC's Climate Models be Validated or Falsified?

The climate models used by the IPCC for their assessment reports were not created with the intent of simulating Earth's climate. For confirmation of that fact, let's return to Dr. Kevin Trenberth's blog post Predictions of Climate at Nature.com's blog ClimateFeedback (my boldface):

> *In fact there are no predictions by IPCC at all. And there never have been. The IPCC instead proffers "what if" projections of future climate that correspond to certain emissions scenarios. There are a number of assumptions that go into these emissions scenarios. They are intended to cover a range of possible self consistent "story lines" that then provide decision makers with information about which paths might be more desirable. But* ***they do not consider many things like the recovery of the ozone layer, for instance, or observed trends in forcing agents****. There is no estimate, even probabilistically, as to the likelihood of any emissions scenario and no best guess.*
>
> *Even if there were, the projections are based on model results that provide differences of the future climate relative to that today.* ***None of the models used by IPCC are initialized to the observed state and none of the climate states in the models correspond even remotely to the current observed climate. In particular, the state of the oceans, sea ice, and soil moisture has no relationship to the observed state at any recent time in any of the IPCC models. There is neither an El Niño sequence nor any Pacific Decadal Oscillation that replicates the recent past; yet these are critical modes of variability that affect Pacific rim countries and beyond. The Atlantic Multidecadal Oscillation, that may depend on the thermohaline circulation and thus ocean currents in the Atlantic, is not set up to match today's state, but it is a critical component of the Atlantic hurricanes and it undoubtedly affects forecasts for the next decade from Brazil to Europe. Moreover, the starting climate state in several of the models may depart significantly from the real climate owing to model errors.***

In other words, climate models do not include naturally occurring processes that can cause global warming to occur on annual, decadal and multidecadal timeframes. And Dr. Trenberth was very clear with his use of the word "critical". So let's rewrite a portion of the opening sentence of this paragraph … climate models do not include critical naturally occurring processes… Or in even more basic terms, climate models used by the IPCC were never intended to simulate Earth's climate. The models were intended to simulate a world in which man-made greenhouse gases and other climate forcings were the only way global temperatures could warm and the only way climate could vary. And note the sentence I boldfaced in the first paragraph above. He wrote that climate models "…do not consider…observed trends in forcing agents." That is, the forcings used to drive climate models do not agree with the observations-based data for those forcings. In other words, even the inputs to the models have no relationship with reality. Is that one of the side effects of using forcings as tuning knobs?

From the quote, Dr. Trenberth, as a scientist and a lead author of three IPCC reports, is acknowledging the existence and the importance of the naturally occurring processes. But he is also stating that the IPCC ignores those <u>critical</u> processes. Why, as a scientist, would Dr. Trenberth ignore such <u>critical</u> processes? It's not just Dr. Trenberth. Why would the rest of the climate science community ignore those <u>critical</u> processes in their climate models? Many persons believe the answer to the questions is, because the direction of the development of climate models to be used by the IPCC was not established by scientists; climate model development was directed by politicians. Keep in mind, the IPCC is a political body, not a scientific one. The IPCC, as a political body, uses climate scientists to achieve political agendas. And those politicians force the direction of research through funding.

SUMMARY

Because the climate models used by the IPCC were never intended to simulate Earth's climate, the models cannot be falsified. That is, it is impossible to prove climate models wrong using observations-based data because climate models were never intended to replicate Earth's climate or observations-based data…and they have not relied on observations-based forcings to drive the models.

If data cannot be used to prove climate models are wrong, then, conversely, data cannot be used to prove climate models are correct. And if data cannot be used to prove climate models are right or wrong, the models have no value.

All the public can do now is attempt to understand the sheer magnitudes of those climate model flaws, which is why this book was written.

2.10 – Decadal Global Warming Projections

Climate models used by the IPCC for long-term climate prognostications still cannot simulate coupled ocean-atmosphere processes like El Niño and La Niña that contribute to long- and short-term climate on Earth. As a result, Guilyardi et al. (2009) made the following statement:

> *Because ENSO is the dominant mode of climate variability at interannual time scales, the lack of consistency in the model predictions of the response of ENSO to global warming currently limits our confidence in using these predictions to address adaptive societal concerns, such as regional impacts or extremes (Joseph and Nigam 2006; Power, et al. 2006).*

Yet, even with those fundamental…those basic…climate model flaws, climate modeling groups are now experimenting with decadal climate predictions, in which El Niños and La Niñas have even greater impacts.   Their efforts sound like an incredible wastes of time and money. And as you shall see, they even look to be incredible wastes.

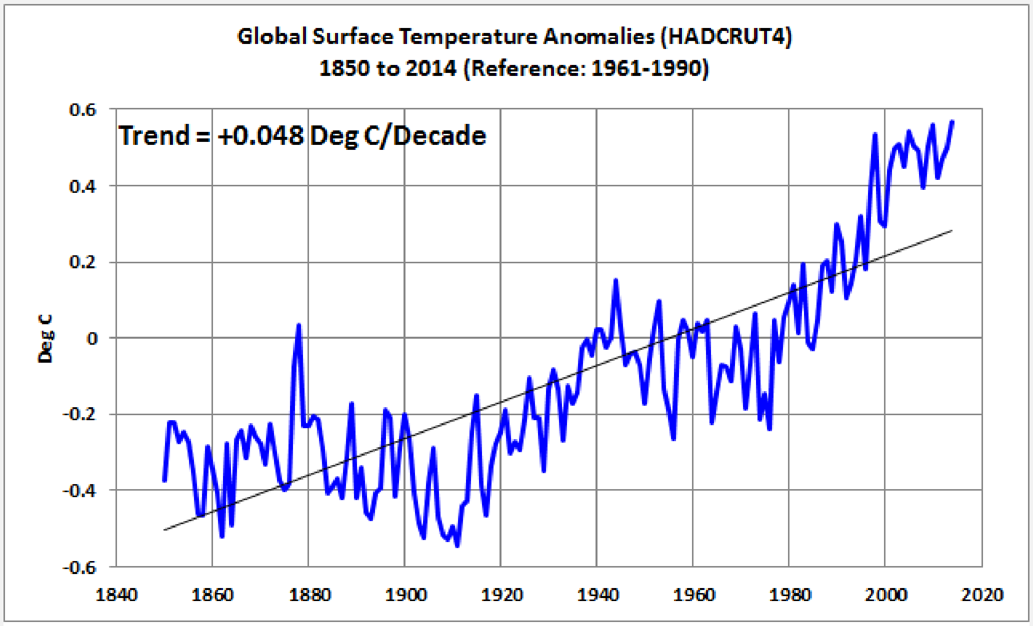


Figure 2.10-1

The primary problem, of course, is the volatility of global surface temperature anomalies. See Figure 2.10-1. Volcanic eruptions and La Niña events cause sudden dip and rebounds in the year-to-year variations, while El Niños cause upward spikes…all on top of the multidecadal variations in surface temperatures.

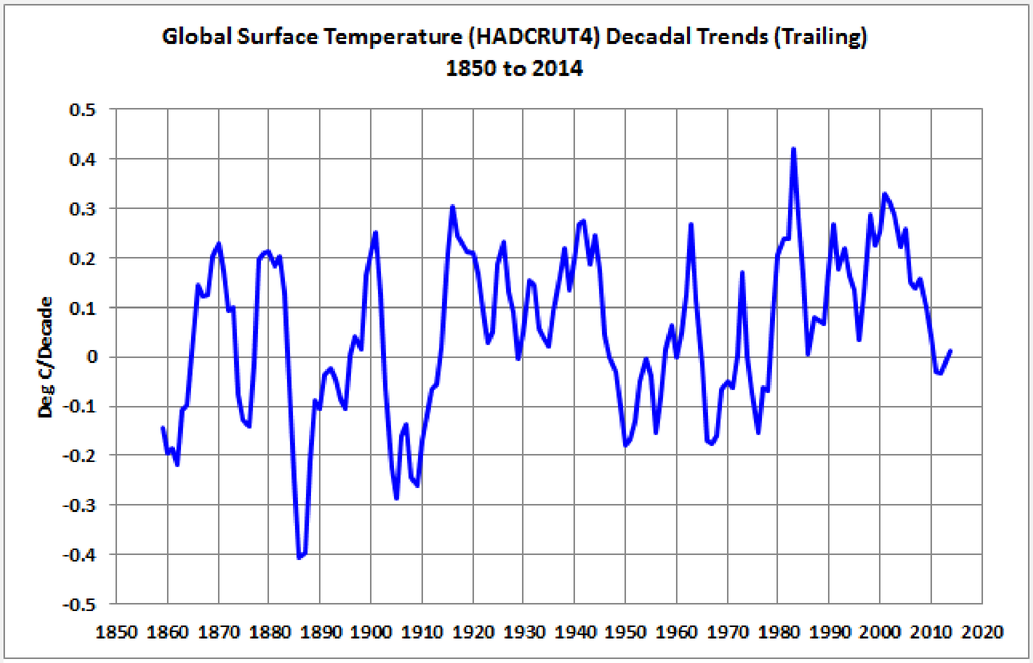


Figure 2.10-2

Figure 2.10-2 shows the decadal trends presented by the HadCRUT4 data shown above. As you'll note, the units of the y-axis (vertical axis) are deg C/decade. I've used the term "trailing" to specify that the data point at 2014 presents the trend for the period of 2005 to 2014. Likewise the data point at 2013 shows the trend in deg C/decade for the period of 2004-2013. Scooting backwards in time to the first data point, it shows the decadal trend of the period from 1850 to 1859. The data indicate that the decadal trends can vary from about -0.4 deg C/decade to more than +0.4 deg C/decade. In more recent decades, there is limited global cooling, so the decadal trends only occasionally drop to zero. Yet the climate modelers, whose models are not simulating climate as it exists on Earth, are attempting to predict what global surface temperatures might be like a decade in the future.

DECADAL GLOBAL WARMING PROGNOSTICATIONS

We'll use Smith et al. (2012) Real-time multi-model decadal climate predictions as our reference for decadal model predictions of global mean surface temperature anomalies. They were kind enough to list the maximum, minimum and mean of the decadal forecasts of global surface temperature anomalies (starting in 2012, and referenced to the period of 1971-2000) in their Table 3. See my Table 2.10-1. We'll exclude the models identified as being "uninitialized", because they are being used as a reference for the "initialized" models being studied.

As a reminder, initialized means the models are run with known observations-based values as starting points. Logically, models that are initialized from observations should perform closer to reality than models that are not initialized.

Note that Smith et al. used what is now an out-of-date version of the UKMO HadCRUT data. That is, the HadCRUT data have been updated since Smith et al.

Table 2.10-1 - Table 3 from Smith et al. (2012)

Table 3 Annual globally averaged temperature anomaly (as in Fig. 8a) from dynamical model and empirical forecasts starting between 1st September 2011 and 1st January 2012

Years	Initialized			Uninitialized			NRL	Reading (AR1)
	Mean	Lower	Upper	Mean	Lower	Upper		
2012	0.32	0.18	0.46	**0.57**	0.27	0.87	**0.52**	0.28
2013	**0.42**	0.22	0.61	**0.61**	0.31	0.90	**0.60**	0.35
2014	**0.54**	0.33	0.76	**0.65**	0.35	0.95	**0.64**	0.38
2015	**0.62**	0.36	0.88	**0.67**	0.36	0.98	**0.63**	**0.40**
2016	**0.63**	0.36	0.91	**0.64**	0.32	0.96	**0.63**	**0.43**
2017	**0.61**	0.34	0.88	**0.62**	0.36	0.87	**0.64**	**0.45**
2018	**0.61**	0.32	0.90	**0.63**	0.37	0.89	**0.66**	**0.47**
2019	**0.64**	0.33	0.94	**0.70**	0.41	1.00	**0.67**	**0.49**
2020	**0.67**	0.38	0.96	**0.72**	0.42	1.02	**0.69**	**0.51**
2021	**0.72**	0.40	1.04	**0.72**	0.45	0.99	**0.72**	**0.53**

The upper and lower values represent the 5–95 % confidence interval diagnosed from the dynamical models ensemble spread. Anomalies are degrees centigrade relative to the average of the period 1971–2000. Forecast mean values highlighted in bold indicate a greater than 50 % chance of exceeding the warmest observed value in the HadCRUT3 dataset (of 0.40 °C occurring in 1998). Initialized mean values that are significantly cooler than the uninitialized means (at the 5 % level based on a one sided *t* test) are underlined

Figure 2.10-3 below presents the last 10 years (2005-2014) of the HadCRUT4 surface temperature data (the current version) and the model mean output of the initialized climate models from Smith et al. (2012) for the 10-year period of 2012 to 2021. Oddly, the temperature anomalies of the models are referenced to the period 1971-2000, so I’ve also referenced the data to the same base years. We’ll correct that in a few moments, but I first wanted to show the model outputs as presented by Smith et al. As shown, the warming rate of global surface temperatures has been incredibly low over the past decade, while the average of the decadal predictions (the consensus, the groupthink) shows the surfaces warming at a rate of about 0.35 deg C/decade for the decade of 2012 to 2021. Obviously, the modelers believe global warming is going to resume at an accelerated pace.

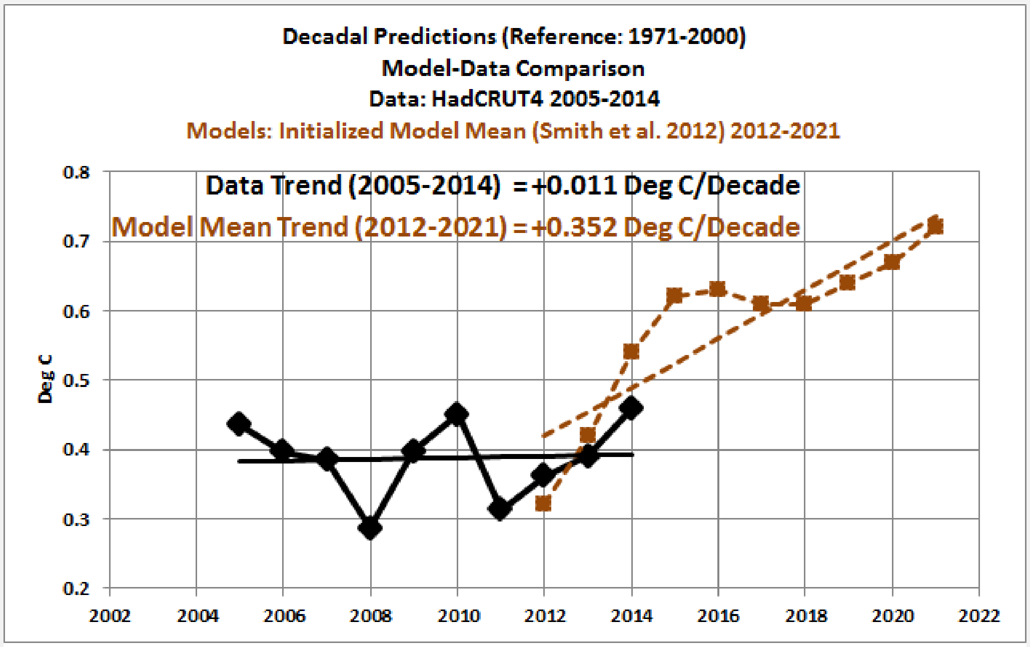


Figure 2.10-3

But climate modelers do not only use the model mean when evaluating the performance of their models. They use the model spread as well. In their Table 3, Smith et al. documented the model spread based on the confidence intervals of 5-95% and listed the corresponding upper (high) and lower (low) values. See Figure 2.10-4. The lower predicted warming rate is about +0.18 deg C/decade, while the upper predicted warming rate is almost 3 times higher at +0.52 deg C/decade.

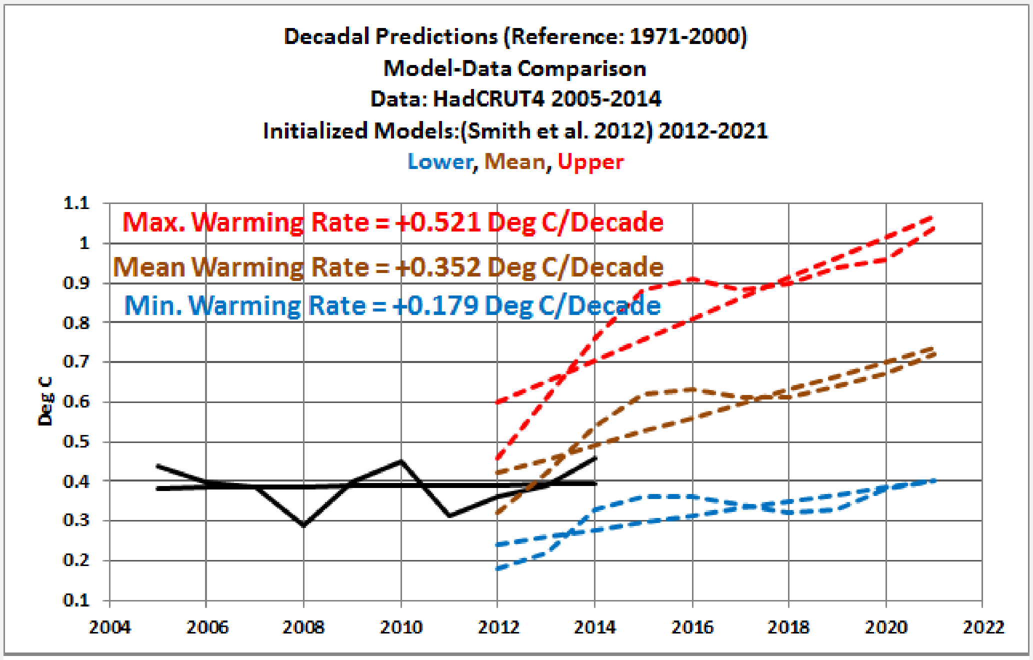


Figure 2.10-4

That's quite a large spread in their predicted warming rates…so large it has limited value. Imagine if your banker told you your life savings might grow with an interest rate that might be 1.8% or 5.2% for the next ten years, but there were no guarantees about those rates, considering they've paid you no interest over the last 10 years. You'd find another bank.

We can see why Smith et al. (2012) used the base years of 1971 to 2000 for their anomalies. It gives them a wider range for failure. Global surface temperatures could continue with no warming for the next 7 years and they could still fall within the uncertainty range, and, by doing so, the modelers would claim victory.

Shouldn't the models making decadal predictions should be aligned with the data at the start year of the prediction? See Figure 2.10-5.

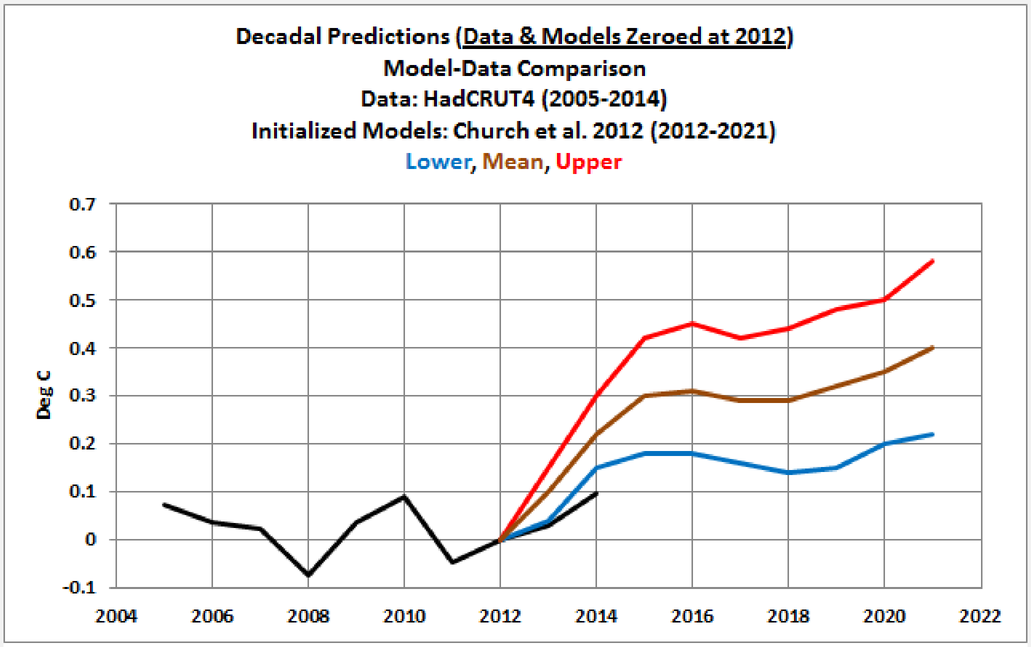


Figure 2.10-5

CHAPTER CLOSING

Decadal global warming prognostications from climate models are still in their infancy. Even so, because there is no way at present to predict the timing, strength and duration of ENSO events, those predictions will be of very limited value. Also limiting the values of those decadal predictions is the wide range of simulated warming rates.

2.11 – Different Ways to Present Climate Model Outputs in Time-Series Graphs: The Pros, the Cons and the Smoke and Mirrors

You'll find the outputs of climate models presented a number of ways in climate studies/reports and in this book.

For the most part, I use two types of model averages. Depending on the topic and what's readily available, I most often present the multi-model mean. Those averages of model outputs are readily available at the KNMI Climate Explorer, specifically from their Monthly CMIP5 scenario runs webpage. How the multi-model mean is calculated: ensemble members of the models with multiple runs are averaged before they're averaged with the averages from other modeling groups and the single model runs from other groups that have not made multiple runs. I other words, the multi-model mean is an average of model averages and single model runs.

At other times, like in this chapter, I'm presenting the averages of all of the individual model runs, which I refer to as the ensemble member mean. A model-data comparison of global surface temperatures from 1861-2014 is shown in Figure 2.11-1. They're clean graphs. That is, there are only two variables to compare visually: the data (in this case the surface temperature data from Berkeley Earth) and the ensemble member mean (the average of the 81 simulations of global surface temperatures of the models stored in the Coupled Model Intercomparison Project, Phase 5 (CMIP5) archive.

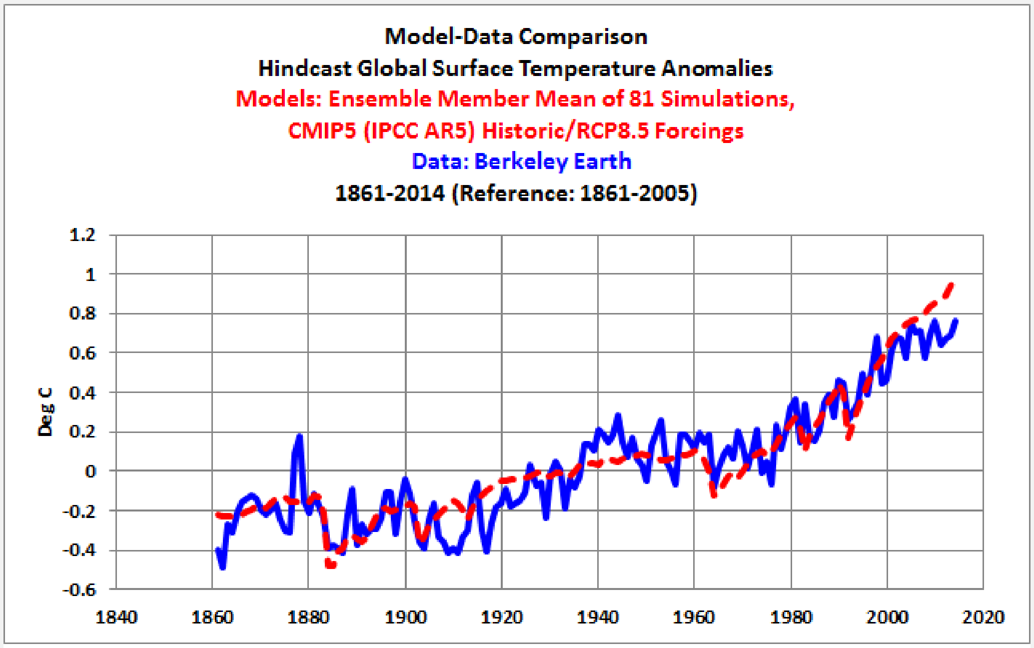


Figure 2.11-1

Climate scientists also use model means in their climate studies. More often, though, in scientific studies, you'll find spaghetti graphs that present all of the model outputs or all of the individual ensemble members. An example is shown in FAQ 10.1, Figure 1 from [Chapter 10, Detection and Attribution of Climate Change: from Global to Regional](#) of the [IPCC's 5th Assessment Report (AR5)](#). See my Figure 2.11-2 (which is the same as Figure 1.12-3). Note that the title of their FAQ 10.1 is "Climate Is Always Changing. How Do We Determine the Causes of Observed Changes?".

FAQ 10.1, Figure 1 from IPCC 5th Assessment Report

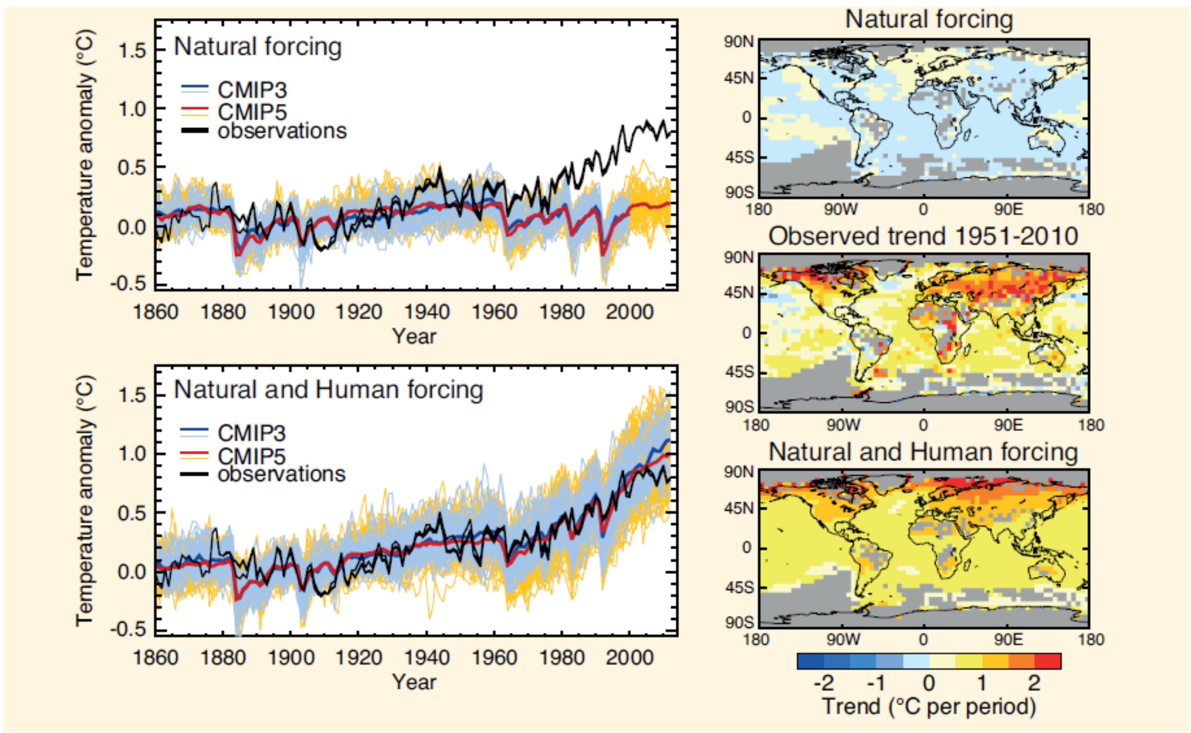
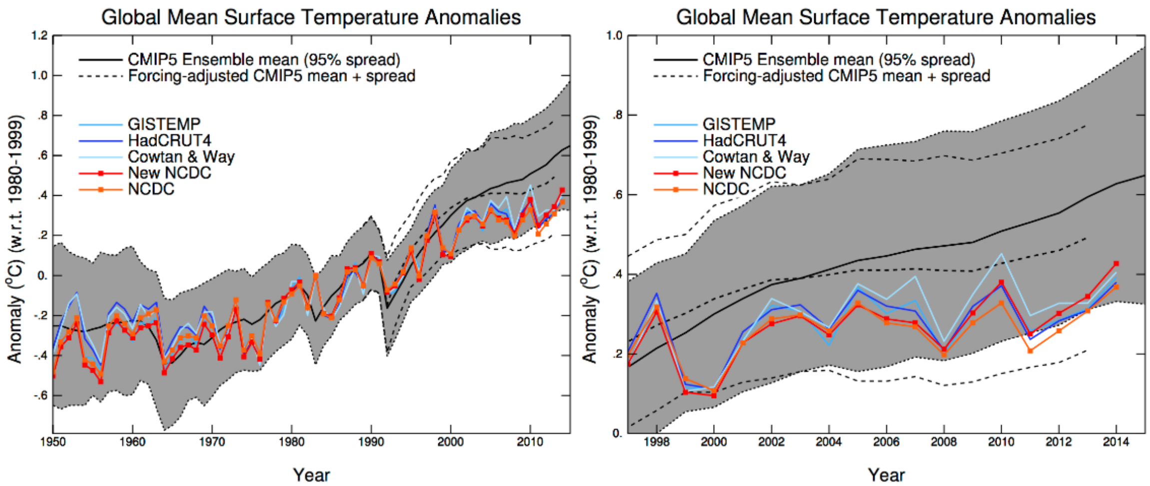


Figure 2.11-2

Each of the yellow lines is a simulation of global surface temperature anomalies…a climate model run from the CMIP5 archive, which was used by the IPCC for their 5th Assessment Report (AR5). And each of the light-blue lines is a climate model run from the archive used for the IPCC's 4th Assessment Report (AR4) from the CMIP3 archive. The red and the darker blue lines are the ensemble averages from the CMIP5 and CMIP3 ensemble members, respectively.

Another way to present the ensemble of climate model outputs is with an envelope of a single color. See Figure 2.11-3, which is the last illustration from the RealClimate blog post [NOAA temperature record updates and the 'hiatus'](#). The author of that blog post is [Dr. Gavin Schmidt, the Director of the Goddard Institute of Space Studies](#). This seems to be the favored way for the climate science community to present climate model outputs.

Climate Model Envelope Presentation from RealClimate Post
NOAA temperature record updates and the 'hiatus'



Source: http://www.realclimate.org/index.php/archives/2015/06/noaa-temperature-record-updates-and-the-hiatus/

Figure 2.11-3

We have to look to Dr. Schmidt's other model-data comparison posts to see what he means by "95% spread". In his annual (2009, 2010, 2011 and 2012) model-data comparisons at RealClimate, Dr. Schmidt states that the 95% range or 95% spread captures 95% of the model runs:

> Everything has been baselined to 1980-1999 (as in the 2007 IPCC report) and the envelope in grey encloses 95% of the model runs.

So, by using that 95% range or 95% spread, they're limiting their leeway a tiny bit…assuming they're also trying to encompass the data with the envelope. And that's a reasonable assumption. Although we can see the recent divergence between the model mean and the data in Figure 2.11-3, the models are argued to be performing acceptably if the data fall within the model envelope.

NOTE

Notice the dashed lines in Dr. Schmidt's illustration, my Figure 2.11-3. Those are the model mean and the upper and lower limits of the model envelopes when the model outputs are adjusted to (supposedly) better represent what has happened in recent years. That's from a Monday-morning-quarterbacking sort-of paper by Schmidt et al. (2015) Reconciling Warming Trends. The abstract reads (my boldface):

> Climate models projected stronger warming over the past 15 years than has been seen in observations. Conspiring factors of errors in volcanic and solar inputs, representations of aerosols, and El Niño evolution, **may** explain most of the discrepancy.

I always enjoy weasel words in abstracts. The use of the word "may" also indicates that the factors they discussed **may NOT** explain most of the discrepancy. It will be interesting to see how well the Schmidt et al. (2015) adjustments match the new CMIP6 models when they are finally posted.

[End note.]

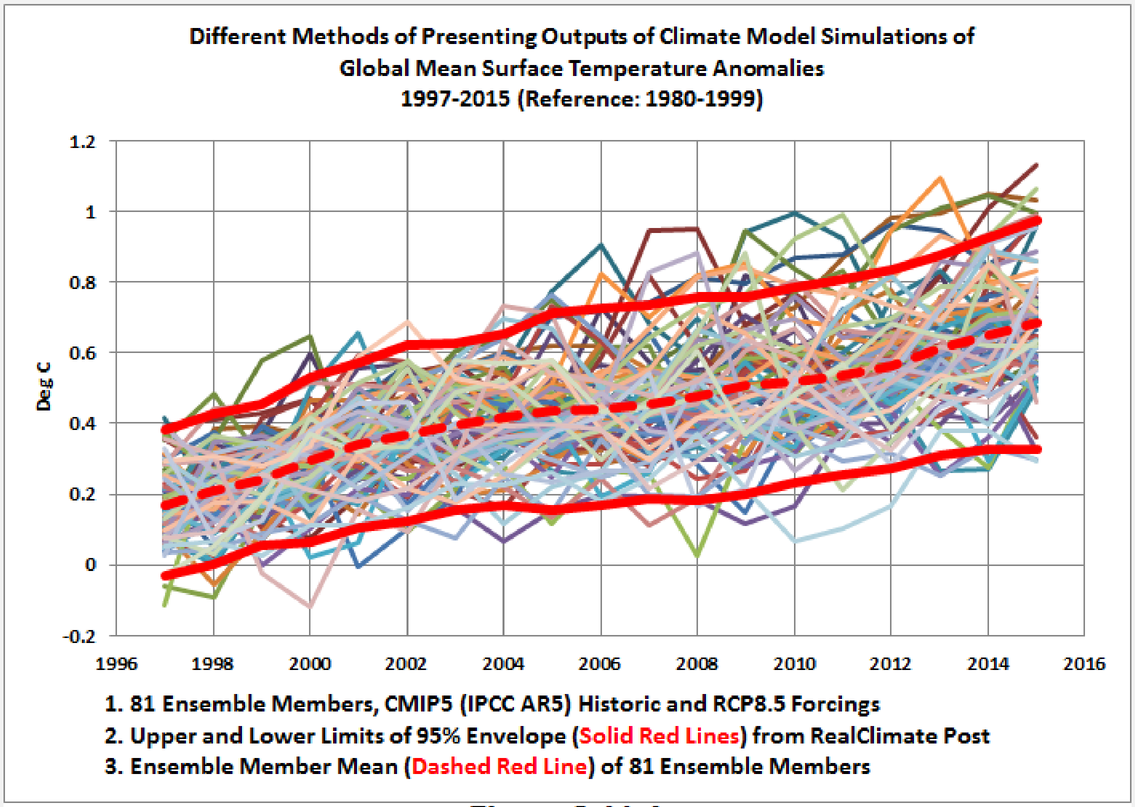


Figure 2.11-4

Dr. Schmidt did not list which of the RCP scenarios he used for his model envelope. It also was not noted in the Schmidt et al. (2015) paper. And there can be minor differences in the short-term (2005 to 2015) model projections depending on the RCP scenario. With that in mind, in Figure 2.11-4, I've compared the upper and lower limits (solid red lines) of the 95% spread from Dr. Schmidt's blog-post illustration to the 81 simulations of global surface temperatures from the CMIP5 archive, with historic and RCP8.5 forcings. Also shown is the average of the 81 ensemble members. They are being provided simply to confirm, as one would expect, that the envelope of the 95% spread does not contain all of the wiggles of individual model runs.

DO NOT ASSUME THE MODEL ENSEMBLE OR 95% ENVELOPE PROVIDES A MEASURE OF UNCERTAINTIES OR PROBABILITIES

Often times, when I present the model mean, a blogger might respond with something to the effect of *you need to present all of the model outputs (the ensemble or the envelope) so that we can see the uncertainties in the models*.

But the ensemble and envelope are simply ways of presenting a collection of models that provide the wrong answers.

For this discussion, I'm going to rely once again on the writings of Dr. Gavin Schmidt of the Goddard Institute of Space Studies. This time, I'm quoting from an appropriately titled article Climate models produce projections, not probabilities in the Bulletin of the Atomic Scientists. There Dr. Schmidt writes (my boldface):

> ***Climate models are amalgams of fundamental physics, approximations to well-known equations, and empirical estimates (known as parameterizations) of processes that either can't be resolved (because they happen on too small a physical scale) or that are only poorly constrained from data.*** *Twenty or so climate groups around the world are now developing and running these models. Each group makes different assumptions about what physics to include and how to formulate their parameterizations. However, their models are all limited by similar computational constraints and have developed in the same modeling tradition. Thus while they are different, they are not independent in any strict statistical sense.*
>
> *Collections of the data from the different groups, called multi-model ensembles, have some interesting properties. Most notably the average of all the models is frequently closer to the observations than any individual model.* ***But does this mean that the average of all the model projections into the future is in fact the best projection? And does the variability in the model projections truly measure the uncertainty? These are unanswerable questions.***

One of the primary reasons that those are unanswerable questions is that climate models are not simulating climate as it presently exists, as it existed in the past, and may exist in the future. Once again, refer to the Nature.com blog post Predictions of Climate by Dr. Kevin Trenberth:

> *None of the models used by IPCC are initialized to the observed state and none of the climate states in the models correspond even remotely to the current observed climate. In particular, the state of the oceans, sea ice, and soil moisture has no relationship to the observed state at any recent time in any of the IPCC models. There is neither an El Niño sequence nor any Pacific Decadal Oscillation that replicates the recent past; yet these are critical modes of variability that affect Pacific rim countries and beyond. The Atlantic Multidecadal Oscillation, that may depend on the thermohaline circulation and thus ocean currents in the*

> *Atlantic, is not set up to match today's state, but it is a critical component of the Atlantic hurricanes and it undoubtedly affects forecasts for the next decade from Brazil to Europe. Moreover, the starting climate state in several of the models may depart significantly from the real climate owing to model errors. I postulate that regional climate change is impossible to deal with properly unless the models are initialized.*

For a further discussion of the uncertainties in climate models, see the 2009 article Uncertainty in Climate Predictions by Nychka et al. Dr. Douglas Nychka is the Director of the Institute for Mathematics Applied to Geosciences at the National Center for Atmospheric Research.

Let's return to Dr. Schmidt's article Climate models produce projections, not probabilities:

> *It may help to reframe the questions in the following way: Does agreement on a particular phenomenon across multiple models with various underlying assumptions affect your opinion on whether or not it is a robust projection? The answer, almost certainly, is yes. Such agreement implies that differences in the model inputs, including approach (e.g. a spectral or grid point model), parameterizations (e.g. different estimates for how moist convective plumes interact with their environment), and computer hardware did not materially affect the outcome, which is thus a reasonable reflection of the underlying physics.*

However, those agreements are also a "reasonable reflection" on the fact that the models are programmed and tuned to provide similar outcomes.

Dr. Schmidt continues (my boldface and underline):

> *Does such agreement "prove" that a given projection will indeed come to pass? No. There are two main reasons for that. One is related to the systematic errors that are known to exist in models. A good example is the consensus of chemistry models that projected a slow decline in stratospheric ozone levels in the 1980s, but did not predict the emergence of the Antarctic ozone hole because they all lacked the equations that describe the chemistry that occurs on the surface of ice crystals in cold polar vortex conditions--an "unknown unknown" of the time. Secondly, the assumed changes in forcings in the future may not transpire. For instance, concentrations of carbon dioxide are predominantly a function of economics, technology, and population growth, and are much harder to predict than climate more than a few years out.*
>
> ***Model agreements (or spreads) are therefore not equivalent to probability statements. Since we cannot hope to span the full range of possible***

> ***models (including all possible parameterizations) or to assess the uncertainty of physics about which we so far have no knowledge, hope that any ensemble range can ever be used as a surrogate for a full probability density function of future climate is futile.***

Dr. Schmidt then attempts to redirect the discussion…with limited success.

THE PROS AND CONS OF THE MODEL MEAN

On the other hand, when I present the model mean in a blog post illustration, someone else might comment, something to the effect of, *the individual simulations are wrong answers, and the average of wrong answers is not a right answer*. That is obviously a very true statement. But the model mean provides us with an answer in which we have interest.

A similar question was posed to Dr. Schmidt on the thread of the 2009 blog post Decadal Predictions at RealClimate:

> *If a single simulation is not a good predictor of reality how can the average of many simulations, each of which is a poor predictor of reality, be a better predictor, or indeed claim to have any residual of reality?*

Gavin Schmidt replied (See "Comment 46 and his answer at 30 Sep 2009 at 6:18 AM):

> *Any single realisation can be thought of as being made up of two components – a forced signal and a random realisation of the internal variability ('noise'). By definition the random component will uncorrelated across different realisations and when you average together many examples you get the forced component (i.e. the ensemble mean).*

Gavin Schmidt used "noise" to describe the random internal variations (chaotic weather) created within the model. He also used "realisation" in place of "ensemble member." The "forced component", which is very important to this discussion, represents how the model responds to the inputs used to drive the models, like man-made greenhouse gases.

To paraphrase Gavin Schmidt, the individual ensemble members contain random noise that is inherent in each model. That noise limits the value of each individual ensemble member. The model mean, through averaging, minimizes model noise, revealing the "forced component". In other words, the model mean is the best-guess approximation of the modelers' assumptions about how climate on Earth is supposed to respond to man-made greenhouse gases.

That's what we're after: how the Earth is supposed to respond to human-induced global warming.

Next, let's refer to a discussion from an obsolete National Center for Atmospheric Research (NCAR) Frequently Asked Questions webpage under the heading of *GIS Climate Change Scenarios*. The link is to an archived version from the Wayback Machine. The original (no longer in service) link was:

http://www.gisclimatechange.org/faqPage.do

NCAR write (my boldface):

> ***Climate models are an imperfect representation of the earth's climate system and climate modelers employ a technique called ensembling to capture the range of possible climate states.*** *A climate model run ensemble consists of two or more climate model runs made with the exact same climate model, using the exact same boundary forcings, where the only difference between the runs is the initial conditions. An individual simulation within a climate model run ensemble is referred to as an ensemble member. The different initial conditions result in different simulations for each of the ensemble members due to the nonlinearity of the climate model system. Essentially, the earth's climate can be considered to be a special ensemble that consists of only one member.* ***Averaging over a multi-member ensemble of model climate runs gives a measure of the average model response to the forcings imposed on the model. Unless you are interested in a particular ensemble member where the initial conditions make a difference in your work, averaging of several ensemble members will give you best representation of a scenario.***

Because we're examining historic model simulations (hindcasts), "scenario" is the past climate on Earth. The model mean is being presented because it gives the best representation of Earth's climate, as measure by the average model response to the historic forcings (anthropogenic CO_2, etc.) imposed on the models.

To paraphrase that: the model mean of all of the models from all of the modeling groups provides us with the consensus (groupthink) answer for how climate is supposed to respond to the forcings used to drive the models.

That's why I will typically illustrate the model mean. It represents the groupthink, the consensus, of the climate modeling groups.

It was nice to see, though, that NCAR (which includes a climate modeling group) admitted that "Climate models are an imperfect representation of the earth's climate system…"

INTRODUCTION TO THE DISCUSSIONS OF CLIMATE MODEL HINDCASTS – LONG TERM

We're going to be looking at the 81 ensemble members of hindcasts of global surface temperatures. See Figure 2.11-5. Most of the models stored in the CMIP5 archive start at 1850, but a few begin in 1861, so, for consistency sake, we'll start the long-term discussions in 1861. At the tail end of the hindcasts, most models use historic forcings through 2005, while a few extend the historic forcings beyond that year, so we'll end the hindcasts in 2005.

Also note that I've referenced the model outputs to the full-term of the hindcast (1861-2005) for the anomalies. That way no one can claim that I've cherry-picked the base years to make the models look bad. (The models do a good job of that on their own; they don't need my help.)

And for this discussion, we're using the Berkeley Earth (BEST) land+ocean surface temperature data as our observations.

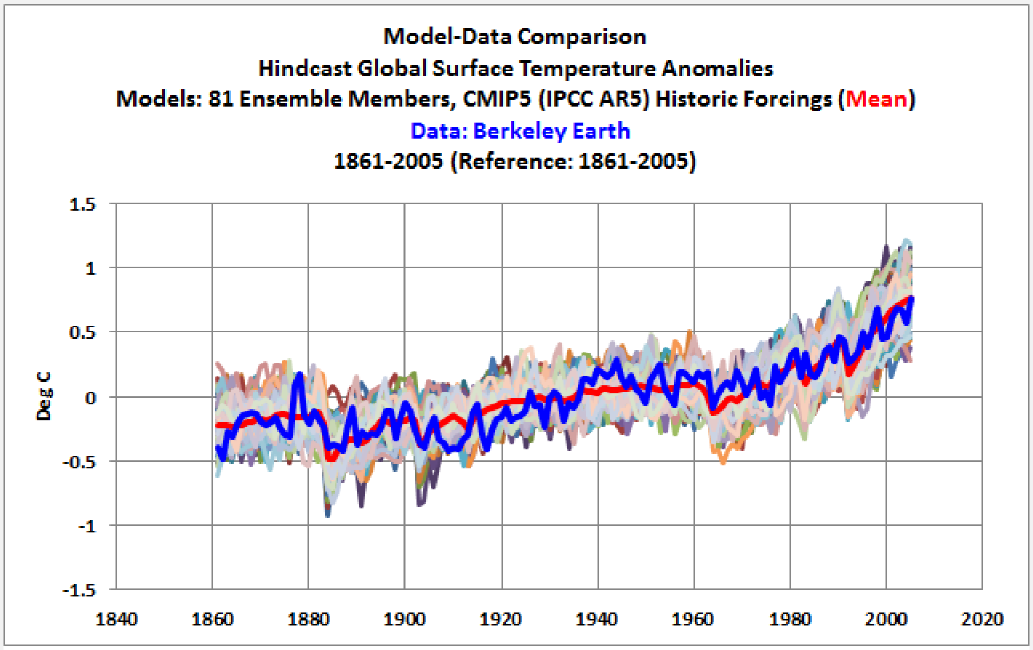


Figure 2.11-5

The data are contained by the upper and lower values of the ensemble, so we're told that the models perform well at simulating global surface temperature anomalies.

THE ILLUSION PROVIDED BY THE ENSEMBLE – LONG TERM

An ensemble of climate models (and a model envelope) gives the misleading illusion that all of the models provide the same basic warming rate, because we focus on the range of the upper and lower values.   For Figure 2.11-6, I've plotted the annual minimum and maximum anomalies from the ensemble, along with the trends of those high and low values. I've also included the data as a reference.

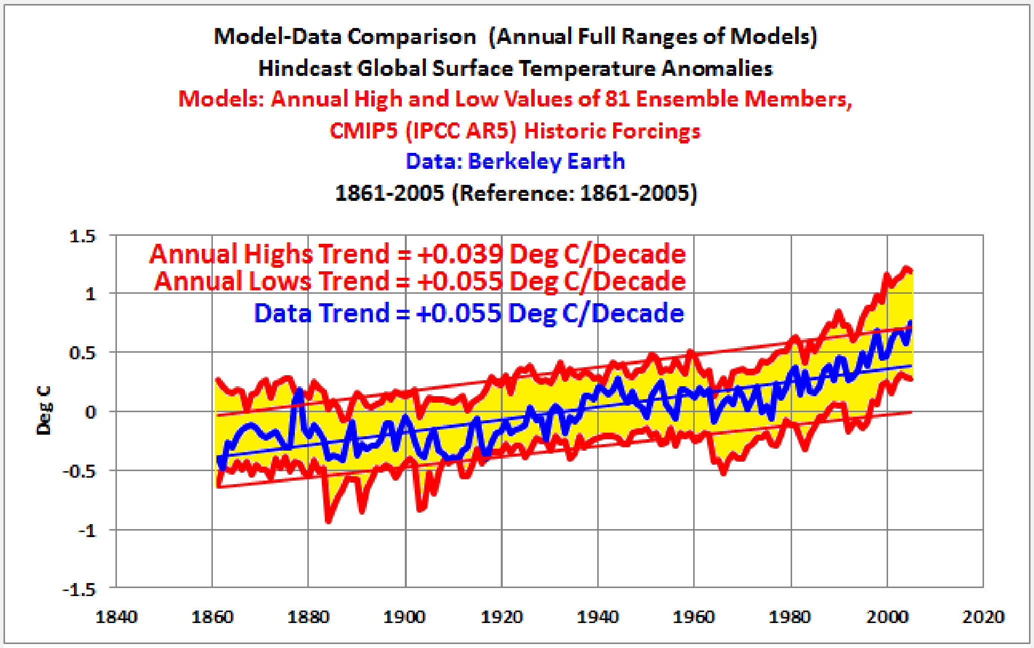


Figure 2.11-6

As shown, the trend of the annual highs is somewhat similar to the data and the annual lows have the same trend of the data. Your eyes are drawn to those similarities in the ensemble…or the envelope when it's used.

THE REALITIES OF THE MODELS CONTAINED IN THE ENSEMBLE – LONG TERM

Figure 2.11-7 presents the ensemble members with the highest and lowest long-term (1861-2005) warming rates. I've also furnished the annual high and low values of the ensemble as a reference.

The ensemble member with the lowest warming rate from 1861 to 2005 has a very low linear trend of about 0.01 deg C/decade, while the model run with the highest trend shows global surface temperatures warming at a very fast rate of 0.082 deg C/decade, noticeably higher than the observed warming rate of 0.055 deg C/decade.

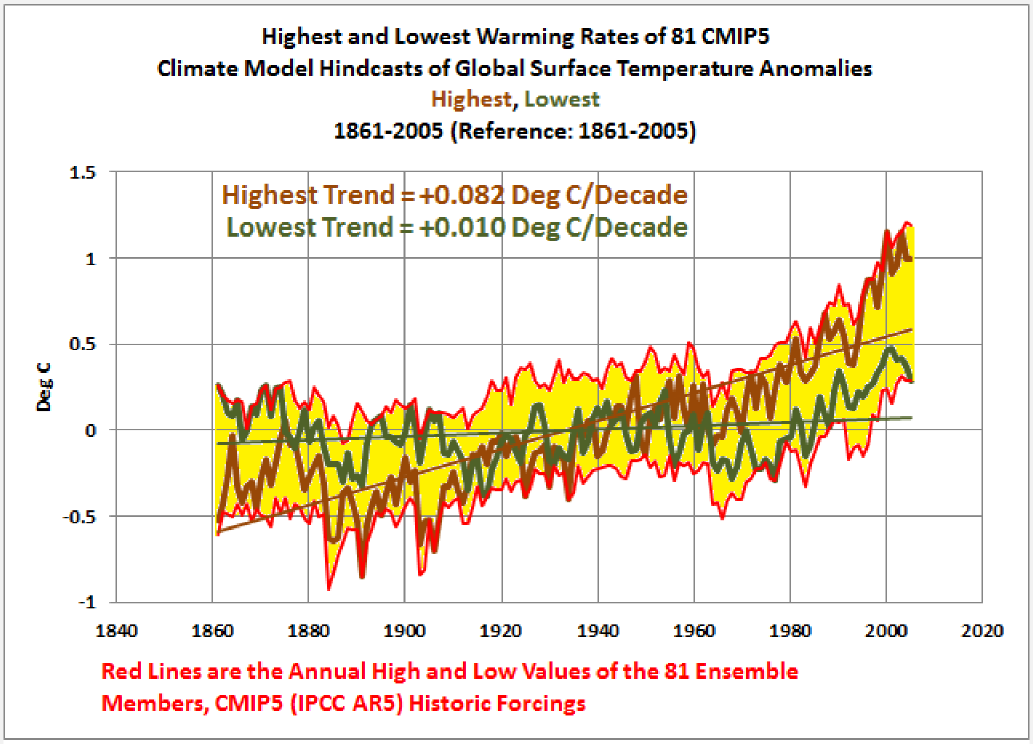


Figure 2.11-7

As noted earlier, the ensemble is made up of climate models that provide the wrong answers.

INTRODUCTION TO THE DISCUSSIONS OF CLIMATE MODEL HINDCASTS – SHORT TERM, RECENT WARMING PERIOD

We'll run through the same sequence of graphs, with the same 81 model hindcasts, using the same base years of 1861-2005 so that I can't be accused of cherry-picking. But in these graphs, we'll only cover the recent warming period, which we'll consider to have started in 1975. Bottom line, the model-data comparisons will run from 1975 to 2005.

We're also going to point out a few things that become obvious over this shorter term.

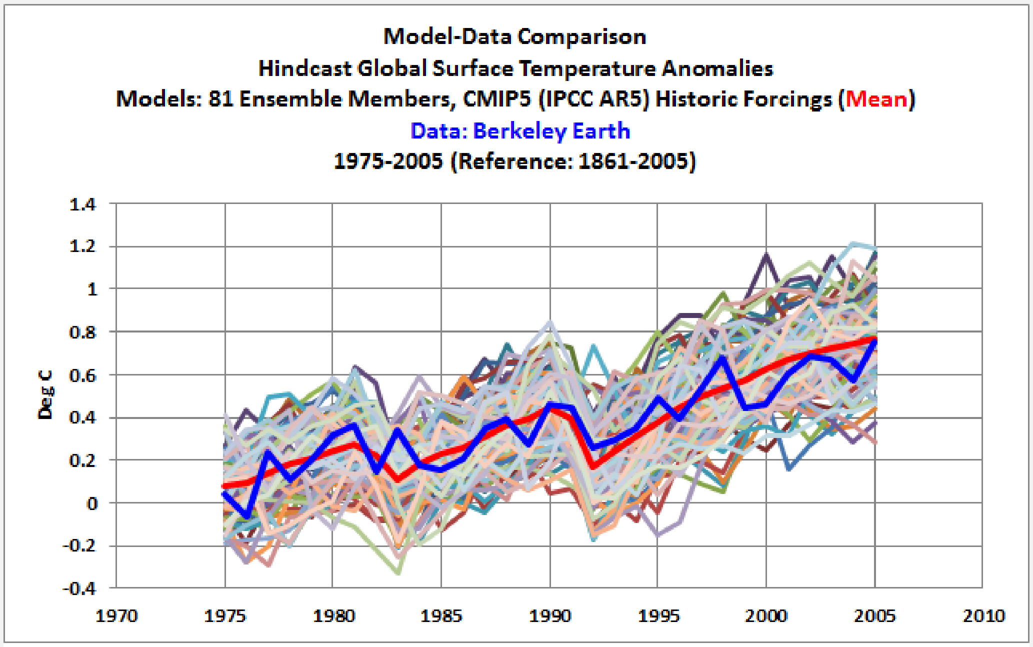


Figure 2.11-8

Figure 2.11-8 presents the 81 simulations of global surface temperature anomalies, along with the ensemble member mean and the Berkeley Earth surface temperature data. The modelers claim victory because the data fall within the range of the models.

THE ILLUSION PROVIDED BY THE ENSEMBLE – SHORT TERM, RECENT WARMING PERIOD

The same illusion exists when we look at a model ensemble (or a model envelope) over the shorter term…during the hindcast warming period of 1975 to 2005. See Figure 2.11-9. The annual lows warm at a rate that's a bit less than the data, and the annual highs show a trend that's a bit higher.

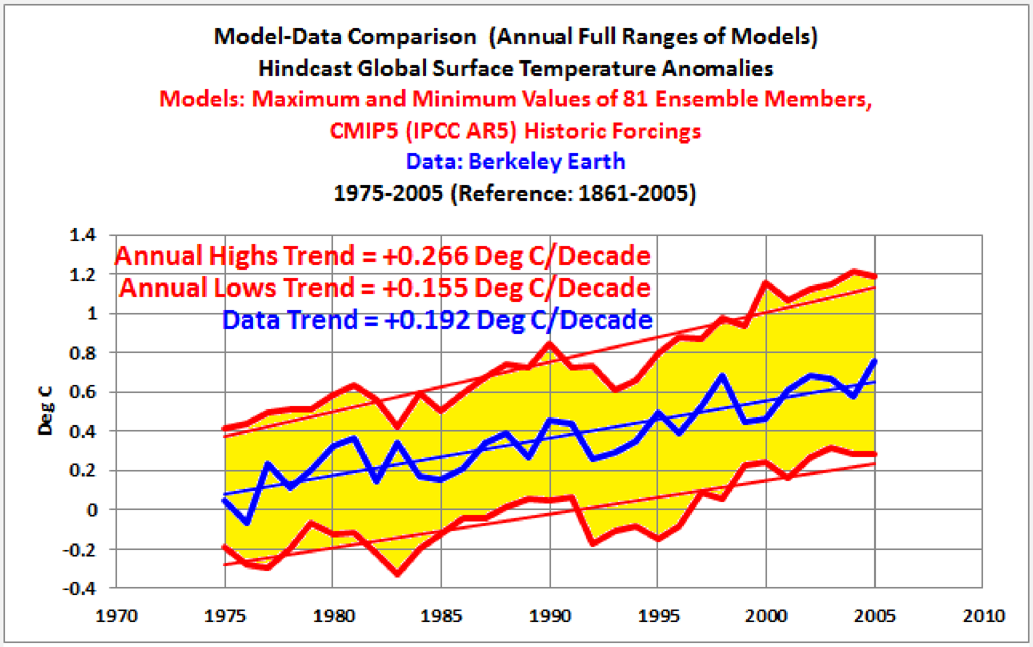


Figure 2.11-9

As I noted earlier, your eyes are drawn to those similarities in trends of the upper and lower values in the ensemble…or the envelope when it's used.

THE REALITIES OF THE MODELS CONTAINED IN THE ENSEMBLE – SHORT TERM, RECENT WARMING PERIOD

But the realities of the models are much different. As shown in Figure 2.11-10, the lowest warming rate of an ensemble member is about +0.06 deg C/decade, while the highest trend of a model run is more than 5 times higher at about +0.33 deg C/decade.

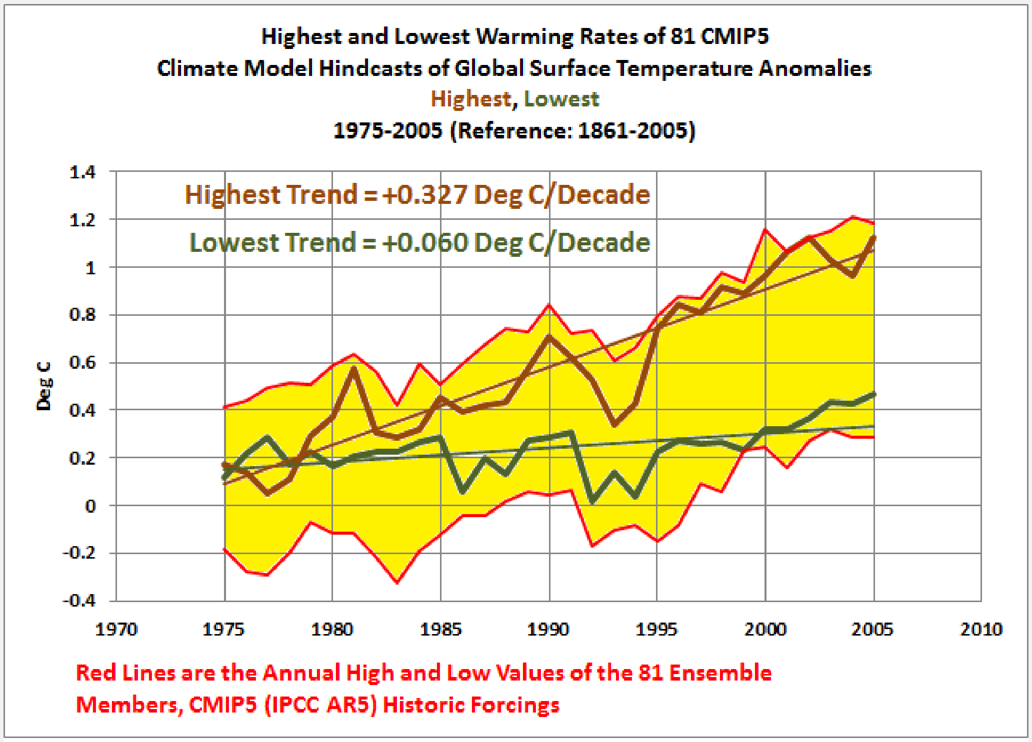


Figure 2.11-10

Bottom line, the climate model ensemble (and the envelope) gives the illusion of much-better model performance.

ACCEPTABLE DATA WARMING RATES BASED ON THE MODEL SPREAD DURING THE PAUSE

The spreads of climate model ensembles and envelopes allow for a wide range of observed global warming rates.

Let's return to the shorter-term graph from Dr. Gavin Schmidt's post NOAA temperature record updates and the 'hiatus' at RealClimate. See Figure 2.11-11. It's the right-hand graph from my Figure 2.11-3. Dr. Schmidt used the base years of 1980-1999 for the anomalies in his illustration.

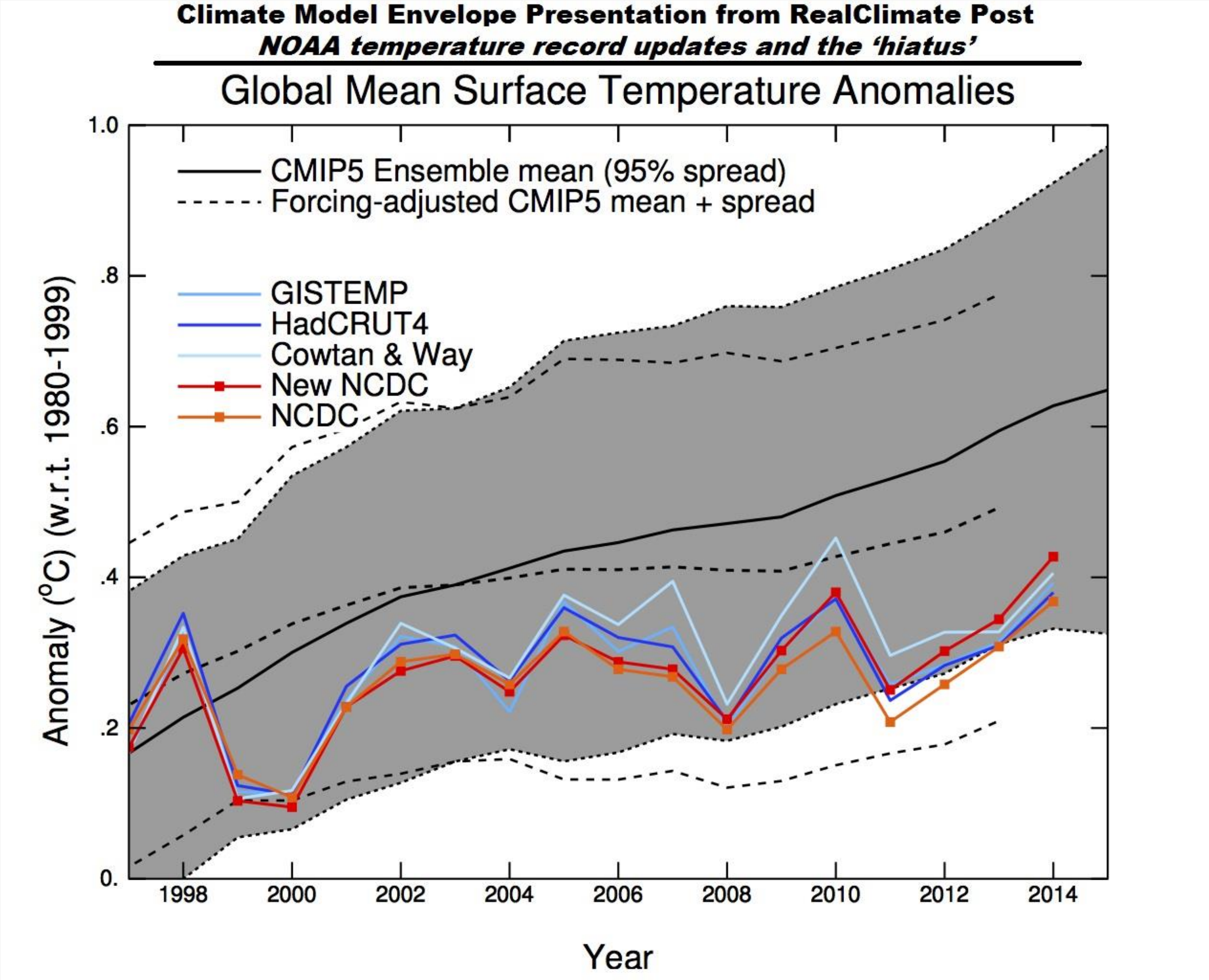


Figure 2.11-11

I've replicated the model envelope and mean in my Figure 2.11-12…not the Monday-morning-quarterbacked adjusted version shown by the dotted lines. And instead of presenting all of the data from the different suppliers, I've used the average. As we can see, the average of the data has been on the verge of being outside of the envelope in recent years.

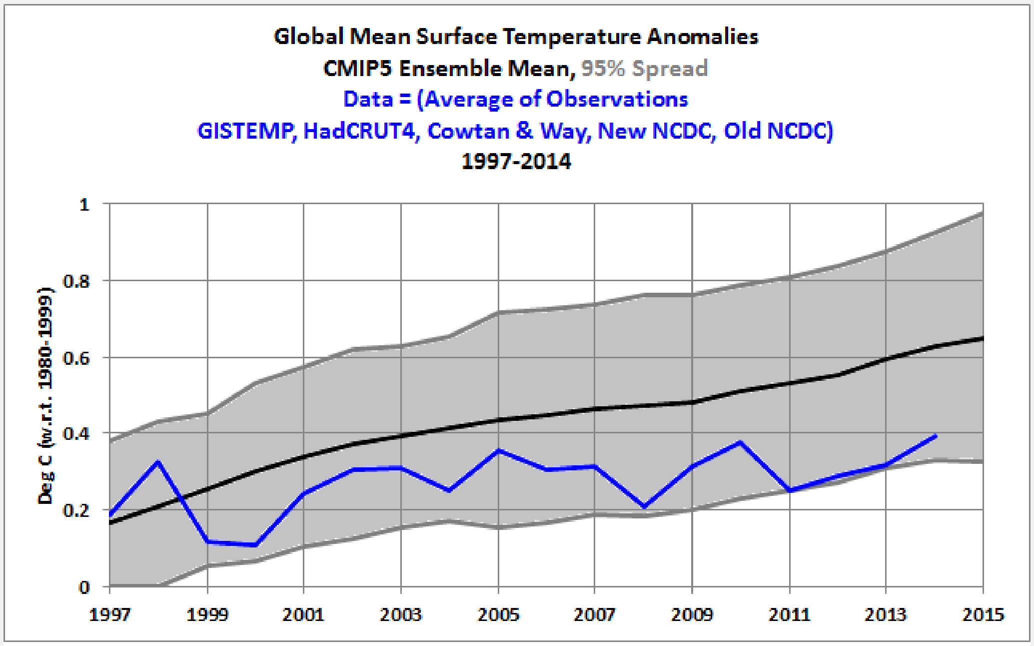


Figure 2.11-12

# # #

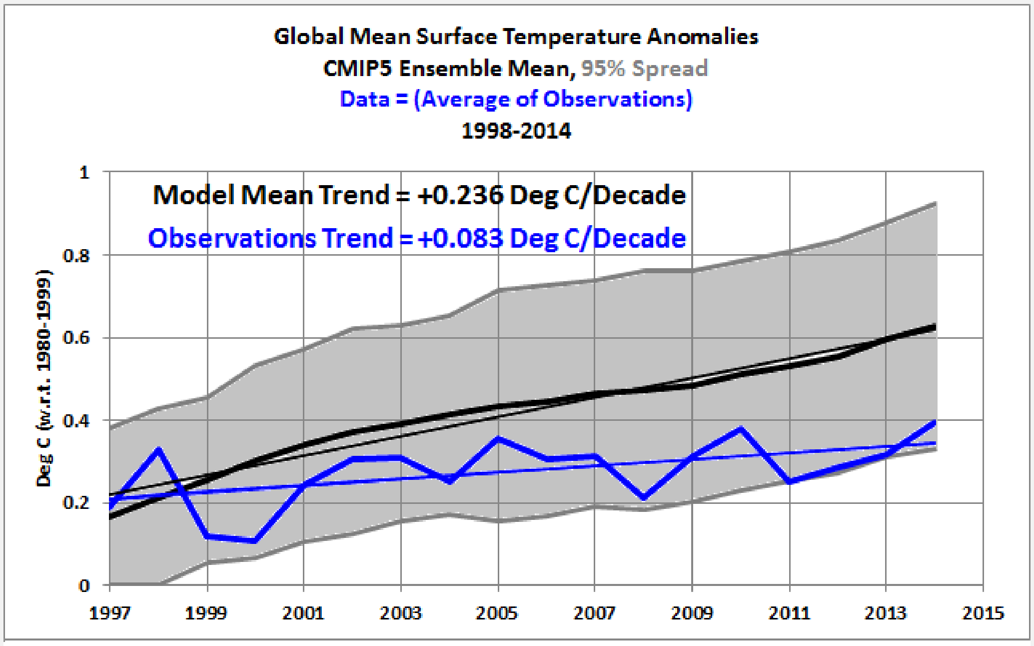


Figure 2.11-13

The linear trends of the data and model mean are shown in Figure 2.11-13. The model mean (the consensus, the groupthink) shows that the global surface temperatures should have warmed at a rate of about +0.24 deg C/decade, while the data mean show that global surface temperatures warmed at about +0.08 deg C/decade. In other words, over the past 17 years, the groupthink was that global surface temperatures should have warmed at a rate that was about 3 times higher than what was observed.

But look at all of the empty envelope space above the model mean. That always draws my attention when I see short-term comparisons of data and the model envelope (or ensemble). Clearly, the model spread is so large that they afford themselves a tremendous amount of leeway.

How much leeway?

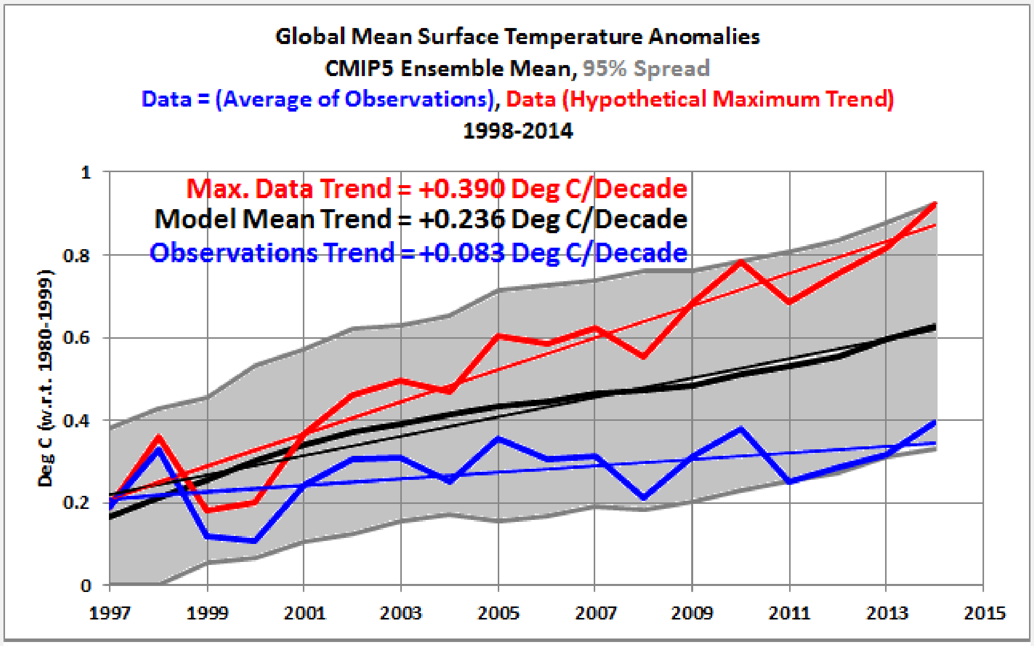


Figure 2.11-14

In Figure 2.11-14, I've added a hypothetical data curve that starts at the 1997 value but reaches the high end of the of the model envelope. In other words, I've pivoted the data at the 1997 start point, maintaining the same annual difference between the data and the trend lines. The hypothetical maximum warming rate that will allow the data to fall within Dr. Schmidt's model envelope is about +0.39 deg C/decade, almost 5 times higher than observed.

That's a lot of leeway.

How much use are a collection of climate models that allow a maximum short-term (17-year) warming rate to be almost 5 times higher than the minimum warming rate? Apparently, the only thing they can really tell us is that global surface temperatures are supposed to warm, but they can't tell us by how much.

CHAPTER SUMMARY

As illustrated and discussed in this chapter, the model ensemble and envelope do not represent probabilities or uncertainties…contrary to popular belief. They are simply a collection of models that indicate how climate had responded in the past to changes in man-made greenhouse gases and might respond in the future, assuming that Earth's actual climate reacts in the same way. Unfortunately, the models bear no relationship to climate as it exists now, as it has existed in the past or as it might exist in the future.

The model envelope and ensemble also provide an illusion of similarities in model performance, when no similarities exist.

And the model envelope and ensemble can offer the modeler with a tremendous amount of leeway when they're testing model performance…so much leeway that the models offer no value.

Then again, we know that some of the climate models are tuned to the short term period we have investigated. The other modeling groups have not yet identified how they tune, or over what period they tune their models, or which metrics they use to tune the models. So we don't know if we're examining model characteristics or how well they are tuned.

The model mean is the average of a collection of models that are not simulating Earth's climate as it exists now, existed in the past or might exist in the future. In that respect the model mean also provides no value in a discussion of model performance. However, the model mean provides us with the groupthink (the consensus) on how a metric like global surface temperatures are supposed to respond to the increases in anthropogenic greenhouse gases. That's why I use the model mean in most of my model-data comparisons.

2.12 – According to the Climate Models Used by the IPCC for their 5th Assessment Report (AR5), How Soon Can We Expect Global Surface Temperatures to Reach 2 deg C above Pre-Industrial Values? – And Why Climate Modelers Refuse to Include Natural Variability in Their Projections

As noted in the Introduction, based apparently at first on a 1970s paper by an economist (not a climate scientist), politicians have sought to create treaties for the past couple of decades that will limit global surface warming to 2 deg C (3.6 deg F) above pre-industrial levels by restricting greenhouse gas emissions.

BUT WHEN DO THE CLIMATE MODELS USED BY THE IPCC FOR THEY 5th ASSESSMENT REPORT (AR5) SAY WE'LL REACH THE SUPPOSED-DOOMSDAY THRESHOLD?

Pre-industrial typically refers to the period before the *industrial revolution*, which is said to have taken during the 18th and 19th centuries. If you need confirmation of that, see the History.com webpage here. Unfortunately, the global land+ocean surface temperature record and the climate model hindcasts stored in the Coupled Model Intercomparison Project, Phase 5 (CMIP5) archives do not extend that far back in time. So we'll use the first 30 years of all models (1861-1890) as our base years for anomalies.

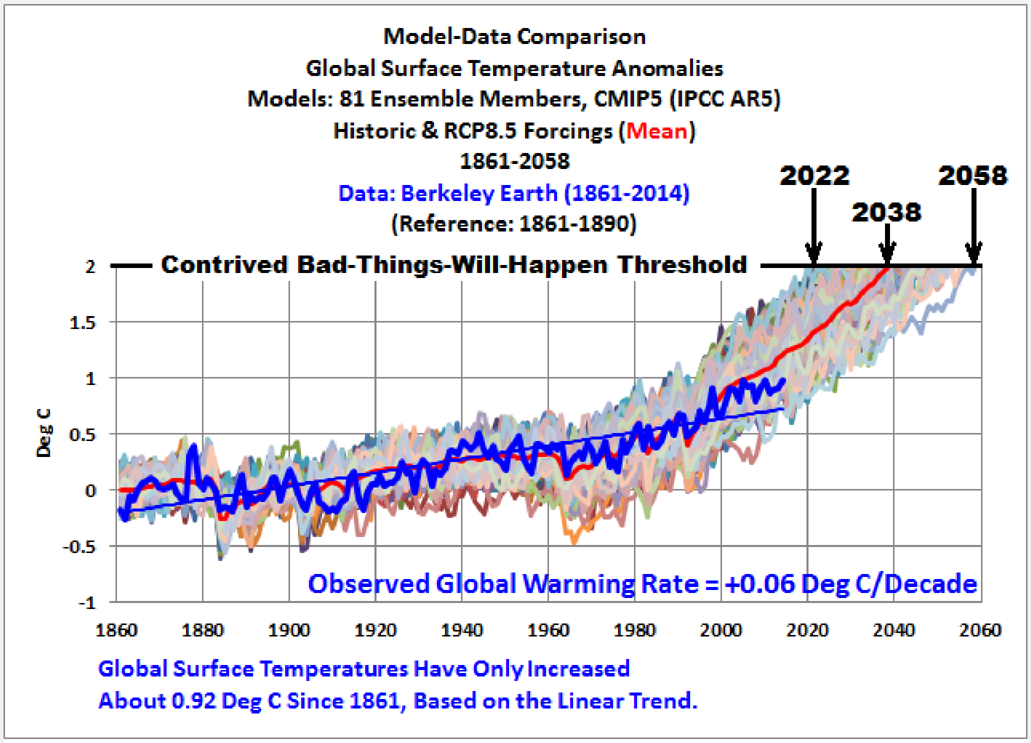


Figure 2.12-1

We'll use the global land+ocean surface temperature (BEST) data from Berkeley Earth for the observations. And we'll use the 81 individual CMIP5 model hindcasts (1861-2005) and projections (2006 to 2100), using the historic and worst-case RCP 8.5 forcings. See Figure 2.12-1. I've added a few notes, as you can see.

Based on the linear trend, global surfaces have only warmed a little more than 0.9 deg C (about 1.7 deg F) in the 154 years from 1861 to 2014. But the ensemble of CMIP5 climate model simulations show global surface temperatures reaching the supposed-to-be-dreaded 2.0 deg C (3.6 deg F) threshold anytime from 2022 (7 years from now) to 2058 (more than 4 decades from now). Let's rephrase that: It took more than 150 years for Earth's surface to warm less than 1.0 deg C (1.8 deg F), but, according to the climate models used by the IPCC, Earth's surface will warm more than 1.0 deg C (1.8 deg F) in the next 7 years to 43 years.

MODELS FAIL TO CONSIDER NATURAL VARIABILITY

Looking at Figure 2.12-1, we can see that the model projections go off at a tangent when compared to the long-term trend of the data. The reason for this: the model projections are aligned with the naturally enhanced warming from about 1975 to 2005, while failing to consider the long-term multidecadal variability shown in the surface temperature record.

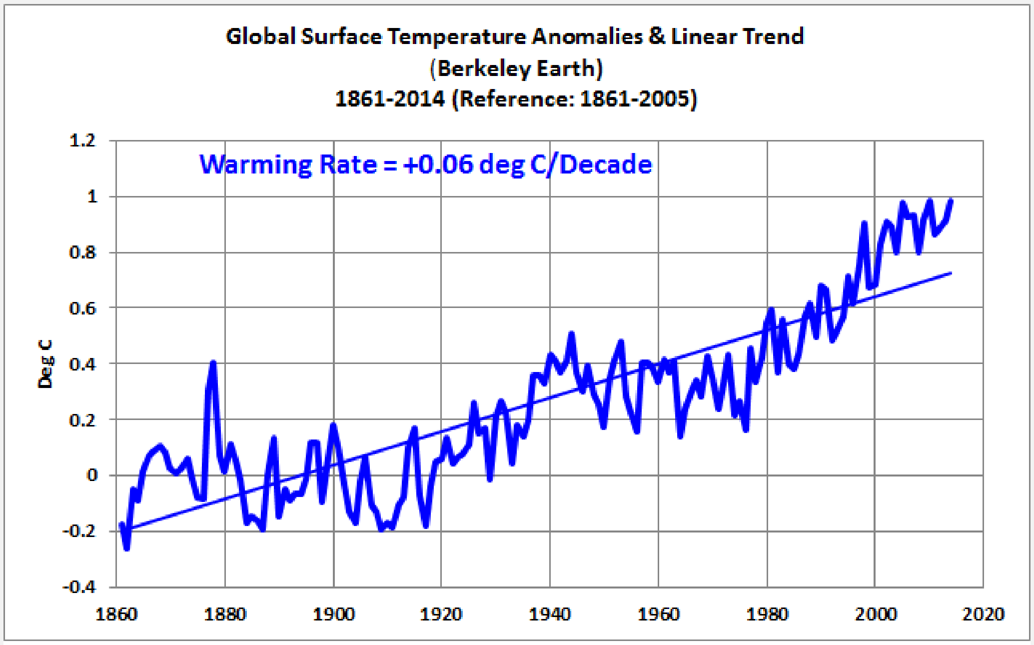


Figure 2.12-2

We can see these multidecadal variations in the surface temperature record in Figure 2.12-2. During some multidecadal periods, the global surface temperature anomalies are above the trend line, and the surface temperature anomalies are below the trend line during other multidecadal periods. Referring again to Figure 2.12-1, the models are out of phase with reality. There's nothing new about that statement.

The multidecadal variations are said to have a frequency of roughly 60 years. That is, it takes roughly 60 years to cycle from minimum to maximum and back to minimum again. The cycle is not perfect. Warming and cooling periods vary length and magnitude.

But for the sake of discussion, we can use a sine wave with a 60-year frequency to show what the modelers have done. See Figure 2.12-3. The sine wave with a 60-year frequency will represent our data…data that has been detrended. It is arbitrarily scaled…in other words, it is not scaled to surface temperatures. The maximums occur at 1885, 1945 and 2005, while the minimums occurred at 1915 and 1975. That roughly (very roughly) aligns with the multidecadal variations in the surface temperature record from 1885 to present. Continuing the 60-year cycle into the future gives us another minimum at 2035, the next maximum at 2065 and yet another minimum at 2095. The red line shows a "model" that aligns with the trend from 1975-2005, and with the maroon dotted line, that "model" trend continues out into the future. As you can see, the model and projection bear no relationship with the underlying cyclical nature of the data.

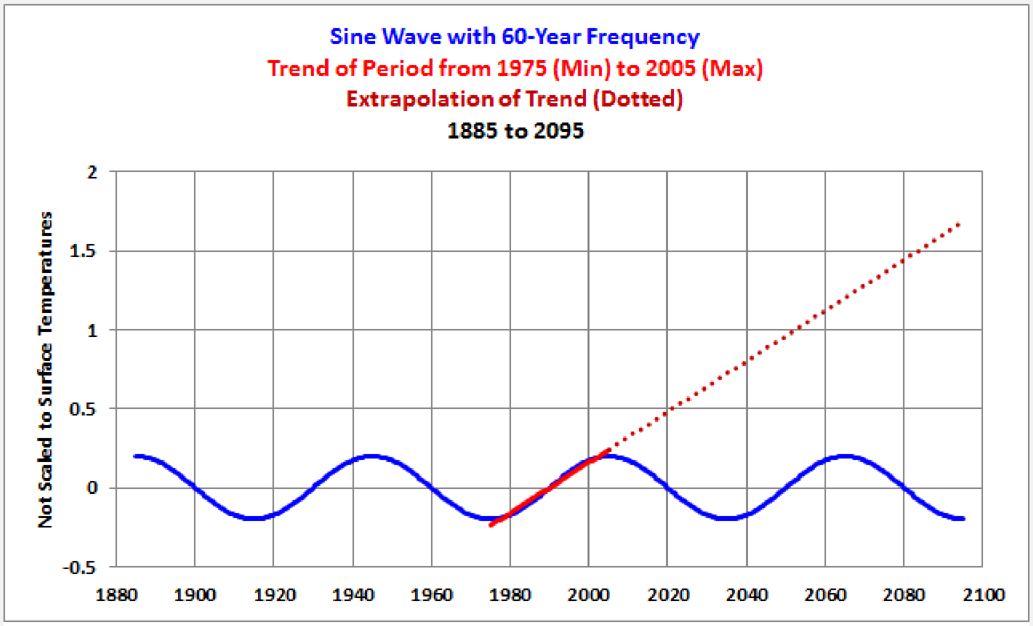


Figure 2.12-3

That's basically what the climate modelers have done. The models align with a naturally occurring upswing in surface temperatures, and as a result, the modelers have failed to consider the future multidecadal variations in their projections caused by the natural enhancement and suppression of global warming.

Imagine if your stockbroker offered you a tip about a stock and you discovered that her or his model looked something like the model shown in Figure 2.12-3. Would you follow the tip and invest your moneys? That's what we're being asked to do.

THE MODEL SPREAD

Something else stands out in the model-data comparison shown in Figure 2.12-1. The model spread at 2014 is comparable to (actually slightly larger than) the warming that has taken place from 1861 to 2014, based on the linear trend. See Figure 2.12-4.

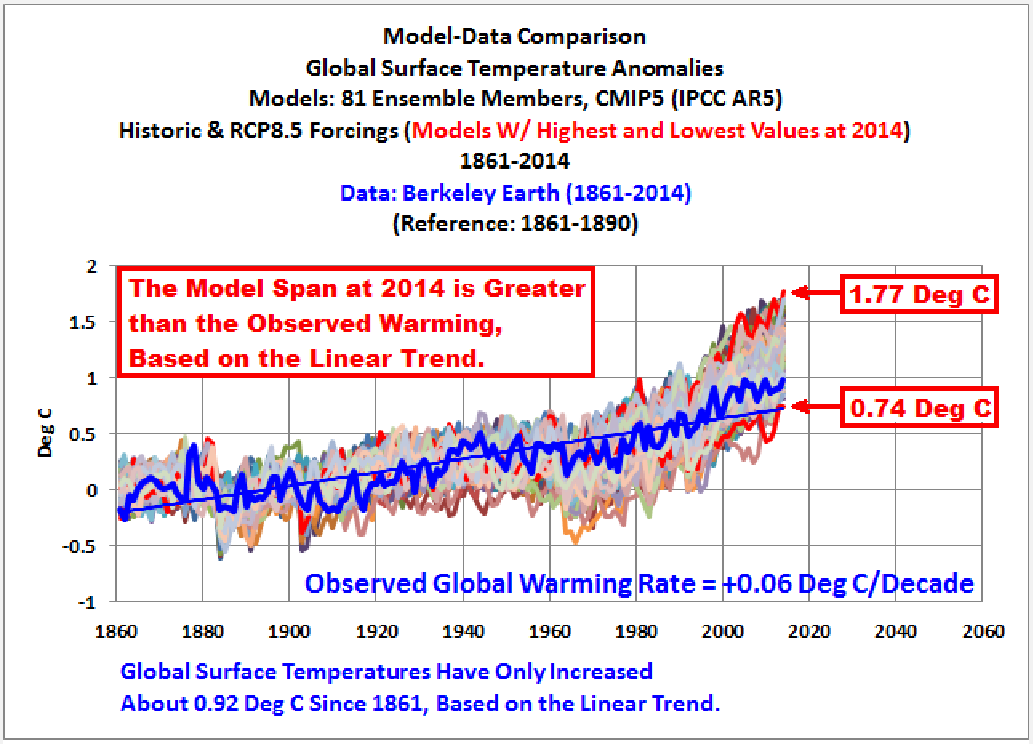


Figure 2.12-4

Once again, the models illustrate how poorly they simulate the primary metric used in discussions of global warming, which is global surface temperatures.

WHY THE MODELERS REFUSE TO CONSIDER MULTIDECADAL VARIABILITY AND EXTEND THOSE VARIATIONS OUT INTO THE FUTURE

My Figure 2.12-5 is Figure 9 from Akasofu (2010) On the recovery from the Little Ice Age. Basically, Dr. Akasofu argues in the paper that the warming we've seen in the instrument temperature record is simply a recovery from the Little Ice Age.

Dr. Akasofu is the Founding Director of the International Arctic Research Center at the University of Alaska Fairbanks and Professor of Physics Emeritus. He writes about his Figure 9 in the Summary of the paper:

> *The temperature rise from 1800-1850 to the present is fairly steady. Therefore, it is not unreasonable to assume the rise after 1900 is a continuation of the same process, namely the recovery from the LIA. Assuming that the recovery from the LIA and the multi-decadal oscillation would continue during the next 100 years or so, the future trend until 2100 is predicted in* ***Figure 9.*** *The observed temperature in 2008 is shown by a red dot with a green arrow. It has been suggested by the IPCC [60] that the thick blue line portion was caused mostly by the greenhouse effect, so their future prediction is a sort of extension of the blue line.*

Figure 9 From Akasofu (2010) *On the recovery from the Little Ice Age*

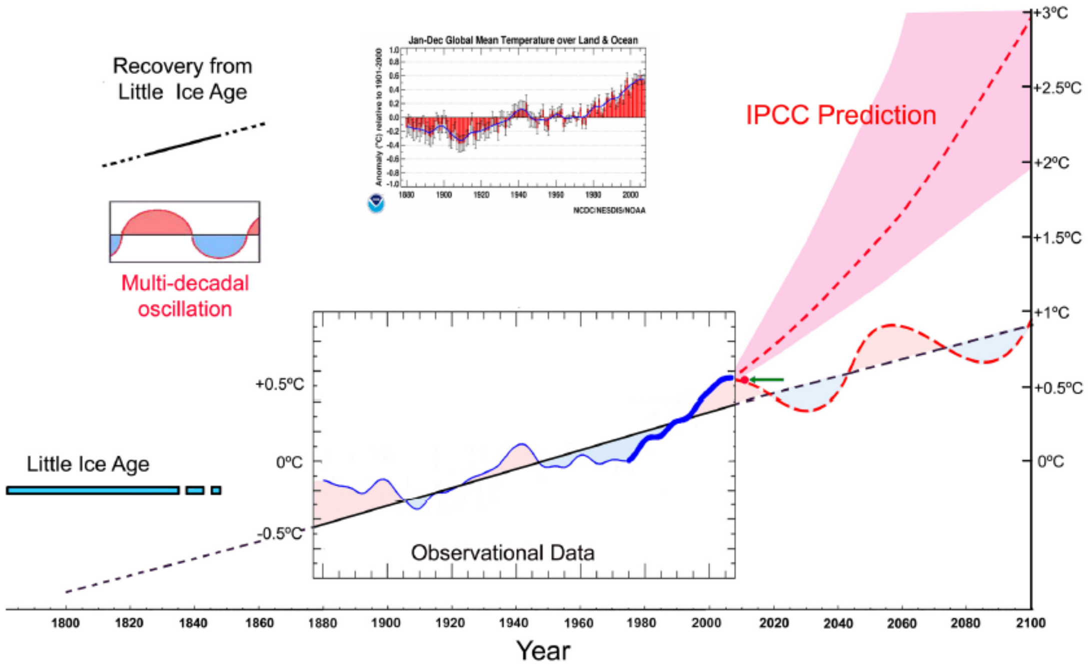


Figure 9. The figure shows that the linear trend between 1880 and 2000 is a continuation of recovery from the LIA, together with the superposed multi-decadal oscillation. It shows also the predicted temperature rise by the IPCC after 2000. It is assumed that the recovery from the LIA would continue to 2100, together with the superposed multi-decadal oscillation. This view could explain the halting of the warming after 2000. The observed temperature in 2008 is shown by a red dot with a green arrow. It has been suggested by the IPCC [60] that the thick blue line portion was caused mostly by the greenhouse effect, so their future prediction is a sort of extension of the blue line.

Figure 2.12-5

Rephrased, Dr. Akasofu assumes the multidecadal variations will continue into the future and they will ride atop an underlying warming (a result of the recovery from the Little Ice Age) that will be comparable to the long-term trend shown by the data.

The last (6th) conclusion from Dr. Akasofu's paper reads:

> *The view presented in this paper predicts the temperature increase in 2100 to be 0.5°C ± 0.2°C, rather than 4° C ± 2.0°C predicted by the IPCC.*

My Figure 2.12-6 is a variation on that theme. In it, we're still comparing model simulations of global surface temperatures and data, all referenced to the pre-industrial time period of 1861 to 1890. But in it, for discussion purposes only, I've extended out to 2100 the model projections and the linear trend of the data.

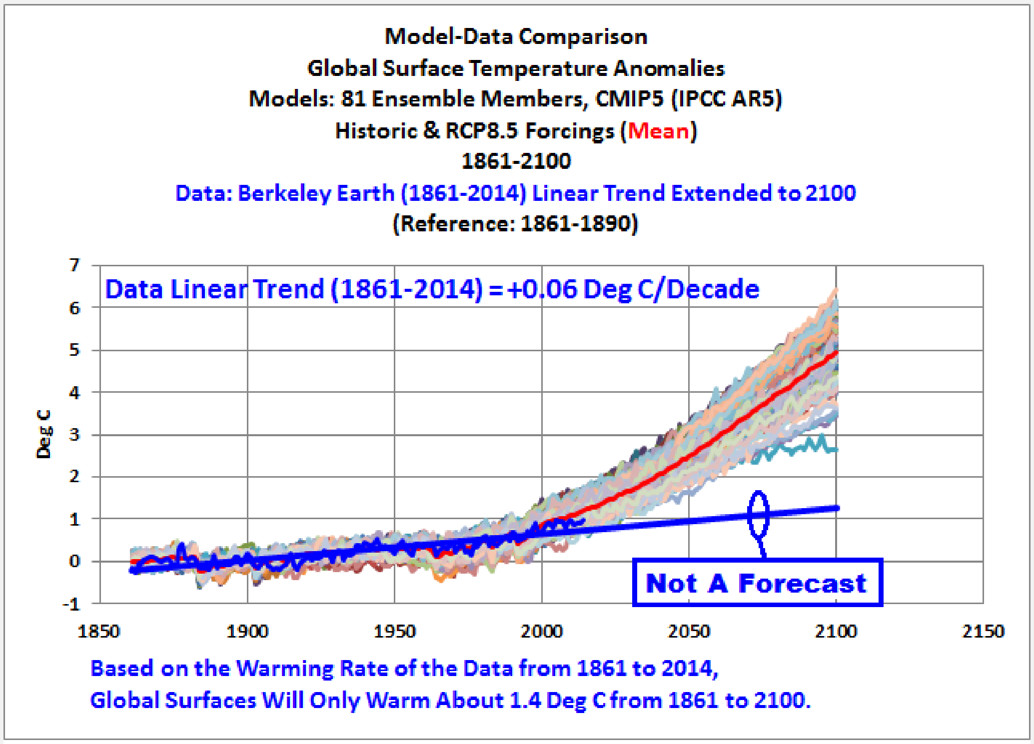


Figure 2.12-6

As shown, if the modelers assumed that the warming would continue at the same long-term rate, there would be little concern about global warming.

And that's a good note on which to end this chapter.

2.13 – Scientific Papers and Letters about Climate Model Failings

Throughout this book, I have and will continue to quote scientific papers and journal letters that discuss the numerous failing of climate models. Many of them are collected here.

BASIC EL NIÑO AND LA NIÑA PROCESSES

El Niño and La Niña events are the dominant mode of natural ocean-atmosphere variability on Earth. They have long-term impacts on temperature and precipitation patterns globally. Of course, climate models do not properly simulate even the most basic of El Niño and La Niña processes.

Bellenger, et al. (2013): ENSO Representation in Climate Models: From CMIP3 to CMIP5 is a recent confirmation of how poorly climate models simulate El Niños and La Niñas and their fundamental processes. Preprint copy is here. The section titled "Discussion and Perspectives" begins:

> *Much development work for modeling group is still needed in order to correctly represent ENSO, its basic characteristics (amplitude, evolution, timescale, seasonal phaselock…) and fundamental processes such as the Bjerknes and surface fluxes feedbacks.*

Notes: 1) "Phaselock" refers to the fact that El Niño and La Niña events are tied to the seasonal cycle. 2) "Bjerknes feedback", very basically, relates to how the tropical Pacific and the atmosphere above it are coupled; i.e., they are interdependent, a change in one causes a change in the other and they provide positive feedback to one another. The existence of this positive "Bjerknes feedback" suggests that El Niño and La Niña events will remain in one mode until something interrupts the positive feedback.

Let me rephrase that quote from Bellenger, et al. (2013): Climate models do not properly simulate how El Niño and La Niña events evolve, their strengths, their timing and how they are tied to the seasonal cycle. Even more telling, according to Bellenger, et al. (2013), "much development work…is still needed" for the basic "fundamental processes" of El Niño and La Niña.

A predecessor to Bellenger, et al. (2013) was Guilyardi, et al. (2009) Understanding El Niño in Ocean-Atmosphere General Circulation Models: Progress and Challenges. It too is a detailed overview of the many problems climate models have in their attempts to simulate El Niños and La Niñas. The authors of that study cite more than 100 other papers. The following is one of the revealing statements in Guilyardi, et al. (2009):

> *Because ENSO is the dominant mode of climate variability at interannual time scales, the lack of consistency in the model predictions of the response of ENSO to global warming currently limits our confidence in using these predictions to address adaptive societal concerns, such as regional impacts or extremes (Joseph and Nigam 2006; Power, et al. 2006).*

In other words, because climate models cannot accurately simulate El Niño and La Niña processes, the authors of that paper have little confidence in climate model projections of regional climate or of extreme events.

ATLANTIC MULTIDECADAL OSCILLATION AND ITS IMPACTS ON PRECIPITATION IN THE NORTHERN HEMISPHERE

The AMO (Atlantic Multidecadal Oscillation) is the subject of the next paper. As will be described and illustrated later in this book, the Atlantic Multidecadal Oscillation presents itself as a naturally occurring variation in the sea surface temperatures of the North Atlantic above and beyond those of global sea surface temperatures. It can contribute to global warming and it can suppress it. Also see Tung and Zhou (2012) Using Data to Attribute Episodes of Warming and Cooling in Instrumental Records. They found that the Atlantic Multidecadal Oscillation contributed about 40% to the global warming since 1950.

In 2013, Ruiz-Barradas, et al. published "The Atlantic Multidecadal Oscillation in Twentieth Century Climate Simulations: Uneven Progress from CMIP3 to CMIP5." The full paper is here. It's important to understand that Ruiz-Barradas, et al. (2013) do not attempt to explain why climate models cannot simulate the features of the Atlantic Multidecadal Oscillation; they start with a basic understanding that the models don't simulate them.

At the beginning of their "Concluding Remarks" they explain why it's important for climate models to be able to accurately simulate the Atlantic Multidecadal Oscillation (my boldface):

> *Decadal variability in the climate system from the AMO is one of the major sources of variability at this temporal scale that climate models must aim to properly incorporate because its surface climate impact on the neighboring continents. This issue has particular relevance for the current effort on decadal climate prediction experiments been analyzed for the IPCC in preparation for the fifth assessment report. The current analysis does not pretend to investigate into the mechanisms behind the generation of the AMO in model simulations, but to provide evidence of improvements, or lack of them, in the portrayal of spatiotemporal features of the AMO from the previous to the current models participating in the IPCC.* ***If climate models do not incorporate the***

> ***mechanisms associated to the generation of the AMO (or any other source of decadal variability like the PDO) and in turn incorporate or enhance variability at other frequencies, then the models ability to simulate and predict at decadal time scales will be compromised and so the way they transmit this variability to the surface climate affecting human societies.***

The only way they could have been clearer would have been to state point blank that climate models will have value only if they are ever able to simulate the decadal and multidecadal characteristics of natural ocean processes. Ruiz-Barradas, et al. (2013) then describe the many problems with climate model simulations of the Atlantic Multidecadal Oscillation. The paper ends with:

> *The current analysis does not provide evidence on why the models perform in the way they do but suggests that that the spurious increase in high 10–20 year variability from CMIP3 to CMIP5 models may be behind the unsatisfying progress in depicting the spatiotemporal features of the AMO. This problem, coupled with the inability of the models to perturb the regional low-level circulation, the driver of moisture fluxes, seem to be at the center of the poor representation of the hydroclimate impact of the AMO.*

In Ruiz-Barradas, et al. (2013), "hydroclimate" appears to mean the variations in precipitation as they relate to drought. They write:

> *Decadal control of hydroclimate from the AMO over North America and Africa is one of the main reasons to worry about having this phenomenon properly incorporated in climate models. Multi-year, summer and fall droughts over North America and Africa have been observationally linked to decadal SST variability in the Atlantic (e.g., Enfield et al. 2001; Ruiz-Barradas and Nigam 2005; Wang et al. 2006; Zhang and Delworth 2006; McCabe et al. 2008; Shanahan et al. 2009; Kushnir 2010; Nigam et al. 2011).*

In summary, according to Ruiz-Barradas, et al. (2013), climate models are still not capable of simulating the variations in time of the Atlantic Multidecadal Oscillation (and the Pacific Decadal Oscillation) along with the associated spatial patterns in the sea surface temperatures. As a result, the model simulations of precipitation are flawed in the Northern Hemisphere.

RESPONSES TO VOLCANIC ERUPTIONS

Of all of the natural occurring factors, volcanic eruptions can have the greatest impacts on short-term global surface temperatures. The sun-blocking aerosols from colossal explosive volcanic eruptions can even overcome the effects of a strong El Niño. There are a number of ways in which explosive volcanic eruptions in the tropics impact atmospheric circulation of the Northern Hemisphere. Climate models even do a poor job of simulating them. Those failings are discussed in Driscoll, et al. (2012) Coupled Model Intercomparison Project Phase 5 (CMIP5) Simulations of Climate Following Volcanic Eruptions.

The abstract of Driscoll, et al. (2012) reads (my boldface):

> *The ability of the climate models submitted to the Coupled Model Intercomparison Project 5 (CMIP5) database to simulate the Northern Hemisphere winter climate following a large tropical volcanic eruption is assessed. When sulfate aerosols are produced by volcanic injections into the tropical stratosphere and spread by the stratospheric circulation, it not only causes globally averaged tropospheric cooling but also a localized heating in the lower stratosphere, which can cause major dynamical feedbacks. Observations show a lower stratospheric and surface response during the following one or two Northern Hemisphere (NH) winters, that resembles the positive phase of the North Atlantic Oscillation (NAO). Simulations from 13 CMIP5 models that represent tropical eruptions in the 19th and 20th century are examined, focusing on the large-scale regional impacts associated with the large-scale circulation during the NH winter season.* ***The models generally fail to capture the NH dynamical response following eruptions.*** *They do not sufficiently simulate the observed post-volcanic strengthened NH polar vortex, positive NAO, or NH Eurasian warming pattern, and they tend to overestimate the cooling in the tropical troposphere. The findings are confirmed by a superposed epoch analysis of the NAO index for each model.* ***The study confirms previous similar evaluations and raises concern for the ability of current climate models to simulate the response of a major mode of global circulation variability to external forcings.*** *This is also of concern for the accuracy of geoengineering modeling studies that assess the atmospheric response to stratosphere-injected particles.*

According to Driscoll, et al. (2012), in climate models, there are fundamental flaws in the response of atmospheric circulation to large changes in external forcings like volcanos.

GLOBAL SURFACE TEMPERATURES

The paper Fyfe, et al. (2011) Skillful Predictions of Decadal Trends in Global Mean Surface Temperature was not about climate model flaws. In fact, the title suggests the models are “skillful”. But on closer examination, you’d discover something very unusual…very unexpected in a paper that claims in the title that the decadal trends in global mean surface temperature have been skillfully predicted by climate models.

Fyfe, et al. (2011) adjusted the model outputs. These were not tuning adjustments. These were adjustments after the fact:

> *….for longer term decadal hindcasts a linear trend correction may be required if the model does not reproduce long-term trends. For this reason, we correct for systematic long-term trend biases.*

Remarkable. The models performed so poorly that Fyfe, et al. (2011) adjusted the models' outputs before they evaluated the models.

Dr. Pielke Sr. wrote a blog post about The Fyfe, et al. (2011) paper back in April 2012 Comments On The Paper "Skillful Predictions Of Decadal Trends In Global Mean Surface Temperature" By Fyfe Et Al 2012. He writes (his underlines and italics):

> This is quite an amazing admission. They write that the *"model does not reproduce long-term trends"* than [sic] "*a linear trend correction may be required*" and "*we correct for systematic long-term trend biases."* The model results are tuned*…*

Let me clarify that. The tuning that Dr. Pielke, Sr. refers to is not the tuning that takes place before the final climate model simulations are run. These are after-the-fact tunings of archived climate model outputs performed by Fyfe, et al. (2011) in order to make the models appear "skillful".

ARCTIC SEA ICE

Arctic sea ice loss outpaced the predictions of an earlier generation of climate models (those stored in the CMIP3 archive), and in the latest generation of models (CMIP5), sea ice loss in the Arctic is still occurring faster than in climate models. These problems are discussed in Stroeve, et al. (2012) "Trends in Arctic sea ice extent from CMIP5, CMIP3 and Observations" [paywalled]. The abstract reads (my boldface):

> *The rapid retreat and thinning of the Arctic sea ice cover over the past several decades is one of the most striking manifestations of global climate change. Previous research revealed that the observed downward trend in September ice extent exceeded simulated trends from most models participating in the World Climate Research Programme Coupled Model Intercomparison Project Phase 3 (CMIP3). We show here that as a group, simulated trends from the models contributing to CMIP5 are more consistent with observations over the satellite era (1979–2011).* ***Trends from most ensemble members and models nevertheless remain smaller than the observed value. Pointing to strong impacts of internal climate variability, 16% of the ensemble member trends over the satellite era are statistically indistinguishable from zero. Results***

> ***from the CMIP5 models do not appear to have appreciably reduced uncertainty as to when a seasonally ice-free Arctic Ocean will be realized.***

The press and climate change enthusiasts have been hyping the loss of Arctic sea ice, but the models simulate it so poorly that the authors of Stroeve, et al. had to conclude that, as far as they were concerned, natural variability causes the bulk of the ice loss.

DROUGHTS & PRECIPITATION

In "Afternoon Rain More Likely Over Drier Soils," Taylor, et al. (2012) wrote:

> *…the erroneous sensitivity of convection schemes demonstrated here is likely to contribute to a tendency for large-scale models to `lock-in' dry conditions, extending droughts unrealistically, and potentially exaggerating the role of soil moisture feedbacks in the climate system.*

Climate models poorly simulate the processes that result in drought, "extending droughts unrealistically."

Further to precipitation, in the 2012 paper, "An Improved Dynamical Downscaling Method with GCM Bias Corrections and Its Validation with 30 Years of Climate Simulations," Xu and Yang wrote:

> *…the traditional dynamic downscaling (TDD) [i.e. without tuning] overestimates precipitation by 0.5-1.5 mm d-1.....The 2-year return level of summer daily maximum temperature simulated by the TDD is underestimated by 2-6°C over the central United States-Canada region.*

The UNFCCC (United Nations Framework Convention on Climate Change) here defines downscaling as:

> *… a method for obtaining high-resolution climate or climate change information from relatively coarse-resolution global climate models (GCMs).*

In simpler terms, downscaling is a method that theoretically allows global climate models to be used to simulate regional climate at more finite levels. As Xu and Yang (2012) noted, however, a widely used form of downscaling both overestimates precipitation and underestimates absolute temperatures. It is important to note that Xu and Yang (2012) were not saying the models underestimated long-term warming; they found modeled summertime temperatures were too cold.

Further to precipitation, there's Stephens, et al. (2010), the title of which is Dreary State of Precipitation in Climate Models. That title certainly gives you an idea of their findings. Stephens, et al. write:

> *...models produce precipitation approximately twice as often as that observed and make rainfall far too lightly.....The differences in the character of model precipitation are systemic and have a number of important implications for modeling the coupled Earth system ....little skill in precipitation [is] calculated at individual grid points, and thus applications involving downscaling of grid point precipitation to yet even finer-scale resolution has little foundation and relevance to the real Earth system.*

EARTH'S ALBEDO

We discussed albedo in *Chapter 1.23 – Notes about Albedo*. As you'll recall, albedo is the fraction of sunlight that's reflected from the Earth back into space. It is basically a measure of the reflectivity of the earth's surface, though clouds play an important role in Earth's albedo. A paper that's critical of climate-model portrayal of albedo is Stephens et al. (2014) The albedo of Earth. We discussed Stephens et al. (2014) in detail in that chapter as well.

Dr. Judith Curry, Professor and Chair of the School of Earth and Atmospheric Sciences at the Georgia Institute of Technology, has a climate-related blog called Climate Etc. Her blog post The albedo of Earth was about Stephens et al. (2014), which has the same title. The following are her concluding remarks:

> *The implications of this paper strike me as profound. Planetary albedo is a fundamental element of the Earth's climate. This paper implies the presence of a stabilizing feedback between atmosphere/ocean circulations, clouds and radiation. Climate models do not capture this stabilizing feedback.*
>
> *The results of this paper also have interesting implications for ice ages, whereby the forcing that is predominant in one hemisphere is felt in the other.*
>
> *The failure of models to reproduce this hemisphere synchronicity raises interesting implications regarding the fidelity of climate model-derived sensitivity to CO_2.*

REGIONAL CLIMATE

Dawson, et al. (2012) in "Simulating Regime Structures in Weather and Climate Prediction Models" noted:

> *We have shown that a low resolution atmospheric model, with horizontal resolution typical of CMIP5 models, is not capable of simulating the statistically significant regimes seen in reanalysis, …….It is therefore likely that the embedded regional model may represent an unrealistic realization of regional climate and variability.*

As you'll recall, CMIP5 stands for Coupled Model Intercomparison Project Phase 5. It is essentially an archive where climate model outputs are stored. The CMIP5-archived models were used by the IPCC for their 5th Assessment Report.

Anagnostopoulos, et al. (2010) in "A Comparison of Local and Aggregated Climate Model Outputs with Observed Data" compared models to data at 55 places around the globe and 70 places in the United States. They write:

> *.... local projections do not correlate well with observed measurements. Furthermore, we found that the correlation at a large spatial scale, i.e. the contiguous USA, is worse than at the local scale.*

METHODS USED TO REDUCE MODELING COSTS

"Parameterization of Instantaneous Global Horizontal Irradiance at the Surface. Part II: Cloudy-sky Component" (2012) by Sun, et al. notes:

> *Radiation calculations in global numerical weather prediction (NWP) and climate models are usually performed in 3-hourly time intervals in order to reduce the computational cost. This treatment can lead to an incorrect Global Horizontal Irradiance (GHI) at the Earth's surface, which could be one of the error sources in modelled convection and precipitation. …… An important application of the scheme is in global climate models….It is found that these errors are very large, exceeding 800 W m-2 at many non-radiation time steps due to ignoring the effects of clouds….*

That is, Sun, et al. are critical of one of the methods that climate modelers use to reduce modeling costs: dividing the day into 3-hour time intervals. They then suggested a way of correcting it that does not greatly increase modeling costs.

SEA SURFACE TEMPERATURES

SST in the following title stands for Sea Surface Temperature, which is one of the variables I've been illustrating and discussing throughout this book. In the Van Haren, et al. (2012) paper "SST and Circulation Trend Biases Cause an Underestimation of European Precipitation Trends," the authors write (my boldface):

> *To conclude, modeled atmospheric circulation and SST trends over the past century are significantly different from the observed ones. These mismatches are responsible for a large part of the misrepresentation of precipitation trends in climate models. The causes of the large trends in atmospheric circulation and summer SST are not known.*

ADAPTATION

Kundzewicz and Stakhiv (2010) write in their editorial "Are Climate Models Ready for Prime Time in Water Resources Management Applications, or Is More Research Needed?":

> *Simply put, the current suite of climate models were not developed to provide the level of accuracy required for adaptation-type analysis.*

NORTH ATLANTIC HURRICANES

Hurricanes are suppressed by El Niño events in the tropical Pacific. This has been known for nearly 30 years, ever since Dr. William Gray published a 2-part study that discussed ENSO as one of the significant factors that influence tropical cyclone development in the North Atlantic. [See Gray (1984) "Atlantic Seasonal Hurricane Frequency. Part I: El Niño and 30 mb Quasi-Biennial Oscillation Influences" and "Atlantic Seasonal Hurricane Frequency. Part II: Forecasting Its Variability."] Dr. Gray notes in the abstract of Part I (my boldface):

> *El Niño events are shown to be related to an anomalous increase in upper tropospheric westerly winds over the Caribbean basin and the equatorial Atlantic. Such* ***anomalous westerly winds inhibit tropical cyclone activity by increasing tropospheric vertical wind shear*** *and giving rise to a regional upper-level environment which is less anticyclonic and consequently less conductive to cyclone development and maintenance.*

In 2012, Shaman and Maloney published "Shortcomings in Climate Model Simulations of the ENSO-Atlantic Hurricane Teleconnection." The abstract begins (my boldface):

> *A number of recent studies have used model projections to investigate how the North Atlantic environment in which tropical storms develop, as well as hurricane activity itself, might change in a warming world. However, accurate projection of the North Atlantic environment in the future requires, at a minimum, accurate representation of its mean state and variability in the current climate. Here we examine one metric of Atlantic basin tropical cyclone variability—its well-documented association with the El Niño-Southern Oscillation (ENSO)—in reanalyses and Intergovernmental Panel of [sic] Climate Change (IPCC) 4th Assessment Report (AR4) twentieth century and Atmospheric Model Intercomparison Project simulations.* ***We find that no individual model provides consistently good representation of ENSO-related variability in the North Atlantic for variables relevant to hurricane activity (e.g. vertical wind shear, genesis potential). Model representation of the ENSO influence is biased due to both inaccurate representation of ENSO itself and***

> ***inaccurate representation of the response to ENSO within the North Atlantic.*** *Among variables examined, ENSO impacts on vertical wind shear and potential intensity were most poorly simulated.*

Granted, those were the models prepared for the IPCC's 4th Assessment Report. But, even the most current, the CMIP5, models still do not correctly represent El Niño and La Niña processes. In addition, the "Atmospheric Model Intercomparison Project" models, also known as AMIP, use sea surface temperature data as inputs to the models as part of the climate model tuning process. Even using the crutch of actual sea surface temperatures, the models could not simulate "the response to ENSO within the North Atlantic." That is a monumental flaw. Finally, I haven't found any recent papers that note **any** improvement in the CMIP5 generation of models with respect to the impacts of ENSO on hurricanes.

GENERAL OVERVIEW OF MODELS

Let's return to Mauritsen, et al. (2012) "Tuning the Climate of a Global Model," [paywalled], which was mentioned in the introduction. (See the preprint edition here.) Mauritsen, et al. (2012) discuss in detail many of the problems, flaws, unknowns, etc., inherent in climate models and what modelers do to tune the models in light of those flaws. It is an eye-opening read.

MODEL BIAS

There is a remarkable paper that explains why the current generation of climate models (CMIP5) is in better agreement among themselves at simulating surface air temperatures than the previous generation (CMIP3) but, as a result, they perform worse. See Swanson (2013) "Emerging Selection Bias in Large-scale Climate Change Simulations." The preprint version of the paper is here. In the Introduction, Swanson writes (my boldface and underline):

> *Here we suggest the possibility that a selection bias based upon warming rate is emerging in the enterprise of large-scale climate change simulation. Instead of involving a choice of whether to keep or discard an observation based upon a prior expectation, we hypothesize that this selection bias involves the 'survival' of climate models from generation to generation, based upon their warming rate. One plausible explanation suggests this bias originates in the desirable goal to more accurately capture the most spectacular observed manifestation of recent warming, namely the ongoing Arctic amplification of warming and accompanying collapse in Arctic sea ice. However, fidelity to the observed Arctic warming is not equivalent to fidelity in capturing the overall pattern of climate warming.* ***As a result, the <u>current generation (CMIP5) model ensemble mean performs worse</u> at capturing the observed latitudinal structure of warming than the***

> ***earlier generation (CMIP3) model ensemble. This is despite a marked reduction in the inter-ensemble spread going from CMIP3 to CMIP5, which by itself indicates higher confidence in the consensus solution. In other words, CMIP5 simulations viewed in aggregate appear to provide a more precise, but less accurate picture of actual climate warming compared to CMIP3.***

In other words, the current generation of climate models (CMIP5) agrees better among themselves than the prior generation (CMIP3) on how and where surface temperatures have warmed, i.e., there is less of a spread between climate model outputs, because they are converging on the same results. Overall, however, the CMIP5 models perform worse than the CMIP3 models at simulating global temperature. "[M]ore precise, but less accurate."

What I found remarkable about Swanson (2013) was that it explained **why**, **not if**, model performance had grown worse. Apparently, it is common knowledge among the climate science community that CMIP5 models perform worse than the prior generation, CMIP3.

Climate models are growing by leaps and bounds, but in the wrong direction.

CHAPTER SUMMARY

Climate models are portrayed by political entities and the media as splendid tools for portraying what climate will be like in the future. The climate science community, however, is well aware that climate models are deeply flawed. Rarely, if ever, are the models' chronic problems presented to the public and policymakers. In this chapter, I cited scientific studies that showed that the models are flawed at simulating, for example:

- The coupled **ocean-atmosphere processes** of El Niño and La Niña, the world's largest drivers of global temperature and precipitation.
- Responses to **volcanic eruptions**, sometimes powerful enough to counteract the effects of even strong El Niño events.
- **Sea surface temperatures**
- **Precipitation**—globally or regionally
- **Clouds** (as they relate to Earth's albedo)
- Influence of El Niño events on **hurricanes**
- The **coupled ocean-atmosphere processes** associated with decadal and multidecadal variations is sea surface temperatures, which strongly impact land surface temperatures and precipitation on those timescales.

I'll close with a quote from climate scientist Dr. Judith Curry, who is the chair of the School of Earth and Atmospheric Sciences at the Georgia Institute of Technology. As Wikipedia notes:

> *Her research interests include hurricanes, remote sensing, atmospheric modeling, polar climates, air-sea interactions, and the use of unmanned aerial vehicles for atmospheric research. She is a member of the National Research Council's Climate Research Committee.*

Dr. Curry is also the proprietor of the very popular blog Climate Etc. Her recent post, Climate Model Simulations of the AMO, discusses two papers. The first, also discussed in this chapter, is Ruiz-Barradas, et al. (2013) "The Atlantic Multidecadal Oscillation in Twentieth Century Climate Simulations: Uneven Progress from CMIP3 to CMIP5." The second was the recent scientific study by Von Storch, et al. (2013) "Can Climate Models Explain the Recent Stagnation in Global Warming?" Dr. Curry concludes her blog post with the following:

> ***Fitness for purpose?***
>
> *While some in the blogosphere are arguing that the recent pause or stagnation is coming close to 'falsifying' the climate models, this is an incorrect interpretion [sic] of these results. The issue is the fitness-for-purpose of the climate models for climate change detection and attribution on decadal to multidecadal timescales. In view of the climate model underestimation of natural internal variability on multidecadal time scales and failure to simulate the recent 15+ years 'pause', the issue of fitness for purpose of climate models for detection and attribution on these time scales should be seriously questioned. And these deficiencies should be included in the 'expert judgment' on the confidence levels associated with the IPCC's statements on attribution.*

That is, to paraphrase Dr. Curry, it is highly questionable whether climate models are able to tell whether any given indicator of climate change is due to natural or to human causes on decadal to multidecadal timescales. Apparently, the climate science community, with their much-trumpeted numerical models, is no closer than they were decades ago at being able to detect any human fingerprint in global warming or climate change.

GENERAL DISCUSSION 3

On the Reported Record High Global Surface Temperatures in 2015 – And Will Those Claims Continue in 2016?

This is a continuation of General Discussion 2, with updates of many of the graphs presented in it. Because 2015 is not yet over, in this chapter, we'll be focusing on the average surface temperatures for the first 9 months of 2015 (January through September) and using it as a proxy for the full year of data, knowing the last 3 months might change the analysis.

PRELIMINARY NOTE 1: THIS YEAR, A STRONG EL NIÑO IS EVOLVING

Most news sources have been reporting on the development of a strong El Niño in 2015. And rightly so; one has been evolving since early in 2015.

Figure GD-3-1 includes graphs of sea surface temperature anomalies for two NINO regions, from January 1, 2014 to October 7, 2015, based on the weekly Reynolds OI.v2 data here. As discussed, the sea surface temperature anomalies for NINO regions are used by researchers to study the strength, frequency and duration of El Niño and La Niña events. The top graph is for the NINO3.4 region (5S-5N, 170W-120W). NOAA uses the sea surface temperature anomalies for the NINO3.4 region in their Oceanic NINO Index, a.k.a. ONI (but NOAA has and continues to use their monthly ERSST series of sea surface temperature data for the numerous versions of that index). The bottom graph is for the NINO3 region (5S-5N, 150W-90W). The Japan Meteorological Agency (JMA) uses the NINO3 region sea surface temperatures in their El Niño Outlook. See the NOAA map here for the locations of those NINO regions.

NOAA defines El Niño conditions as NINO3.4 region sea surface temperature anomalies equal to or greater than +0.5 deg C (+0.9 deg F). I've highlighted El Niño condition in red in both graphs. The threshold for moderate El Niño conditions is +1.0 deg C (+1.8 deg F) and the threshold for strong El Niño conditions is +1.5 deg C (+2.7 deg F). (We'll confirm those thresholds later in Chapter 3.7 – Ocean Mode: El Niño and La Niña.)

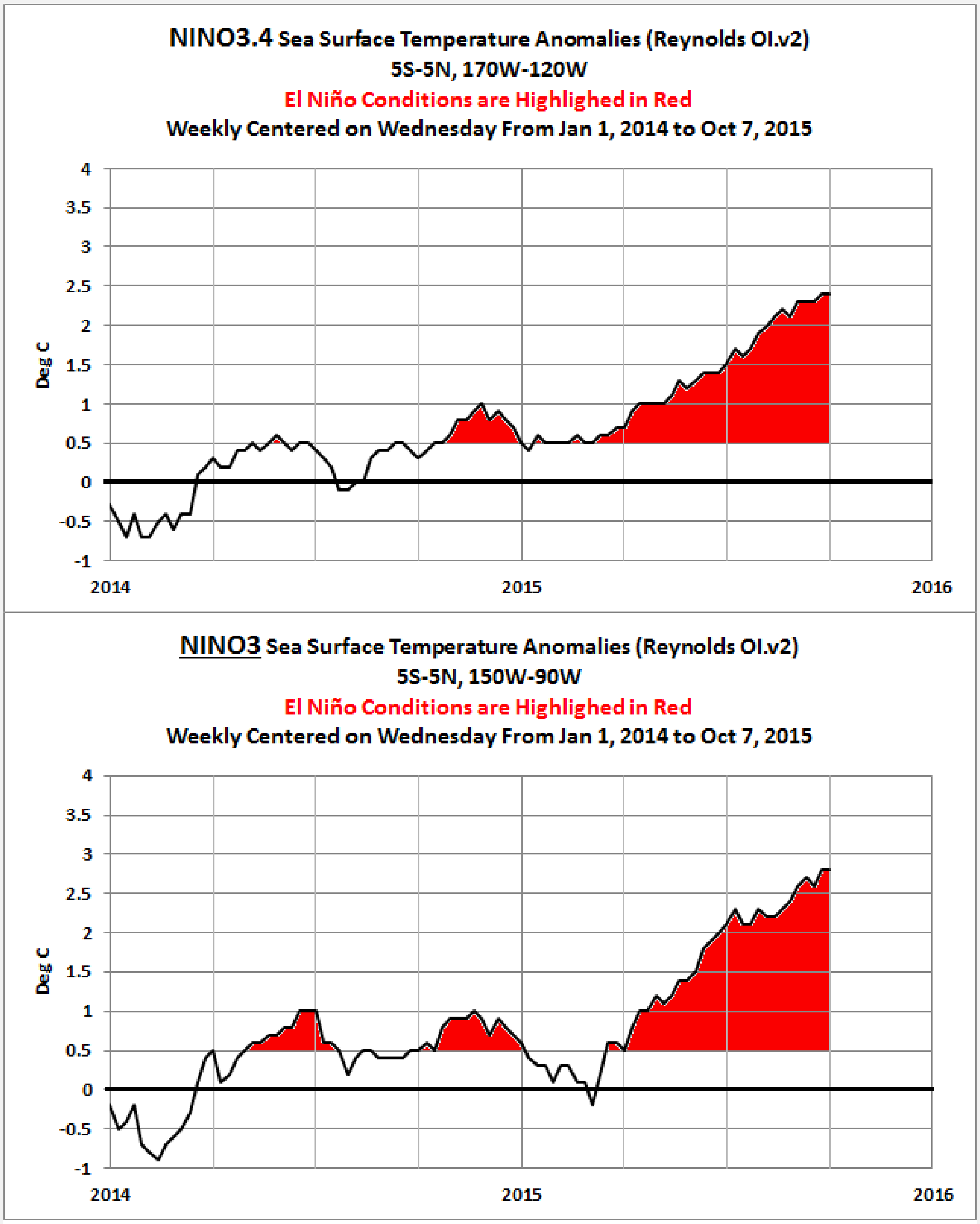


Figure GD-3-1

El Niño conditions developed, decayed and redeveloped in 2014. And referring to the NINO3.4 region, continued into 2015. For the NINO3 region, sea surface temperature anomalies dropped below the threshold of El Niño conditions early in 2015 and then re-entered in March. Or looking at from another perspective, this could be considered a multiyear El Niño based on the NINO3.4 data.

As a result, surface temperature anomalies outside of the tropical Pacific in 2015 may also show the impacts of the El Niño conditions in 2014 and in 2015. (We'll discuss how surface temperatures outside of the tropical Pacific respond to El Niños in Chapter 3.7 – Ocean Mode: El Niño and La Niña.)

Also consider that El Niño events normally peak in November, December and January, because they are tied to the seasonal cycle. The surfaces of the central and eastern equatorial Pacific should continue to warm over the next three months.

PRELIMINARY NOTE 2: MAPS COMPARING SEA SURFACE TEMPERATURE ANOMALIES IN 2014 AND 2015

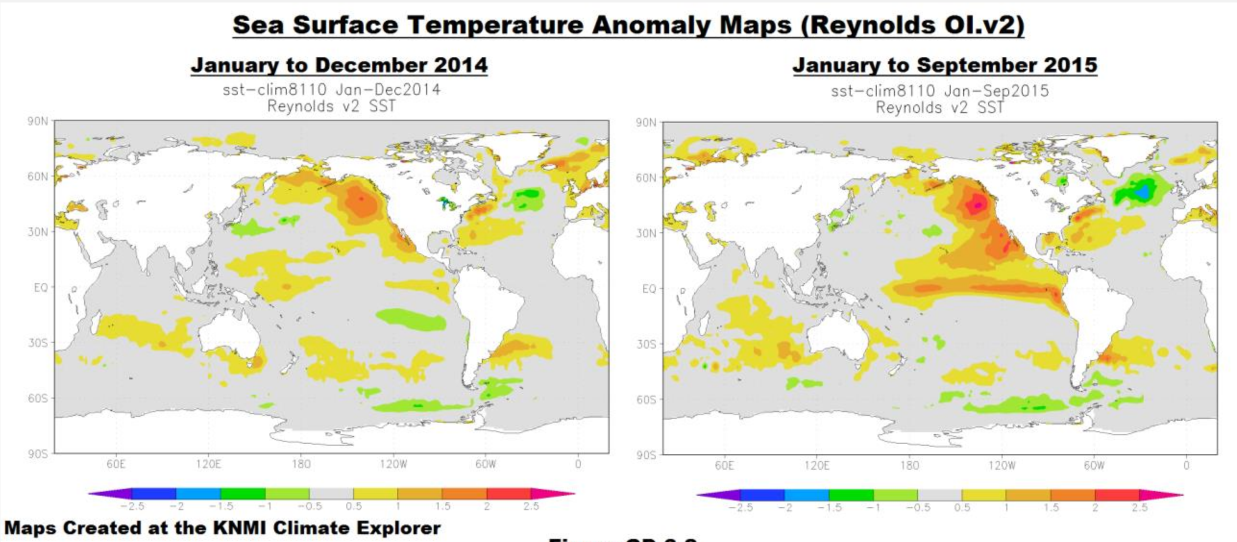


Figure GD-3-2

Using time-series graphs of the individual ocean basins in General Discussion 2, we found that the North Pacific, particularly the area in the eastern extratropical North Pacific known as The Blob, was the primary cause of the reported record-high global sea surface temperatures and record-high global land+ocean surface temperatures in 2014. We also discussed how that unusual warming event in the eastern North Pacific (The Blob) occurred naturally. That is, Mother Nature caused the persistent spike in the sea surface temperatures of The Blob, not man-made greenhouse gases. The Blob is visible off of the west coast of Canada and the United States in the map of sea surface temperature anomalies for 2014, the left-hand map in Figure GD-3-2.

With the continued warming of The Blob in 2015 (see the right-hand map), and with the development of a strong El Niño, we should expect to see similar results…though some of the other ocean basins in 2015 are also responding with upticks this year to the El Niño conditions in the tropical Pacific, as you shall see.

THIS IS A DISCUSSION OF SURFACE TEMPERATURES, BUT LET'S TAKE A QUICK GANDER AT LOWER TROPOSPHERE TEMPERATURE ANOMALIES, TOO, FOR 2015

Figure GD-3-3 includes annual global land+ocean surface temperature anomalies (top graph) and global lower troposphere temperature anomalies (bottom graph) for the period of 1995 to year-to-date (September) 2015. Like the illustrations in General Discussion 2, the data in this chapter (and climate model outputs) have been zeroed at 1995.

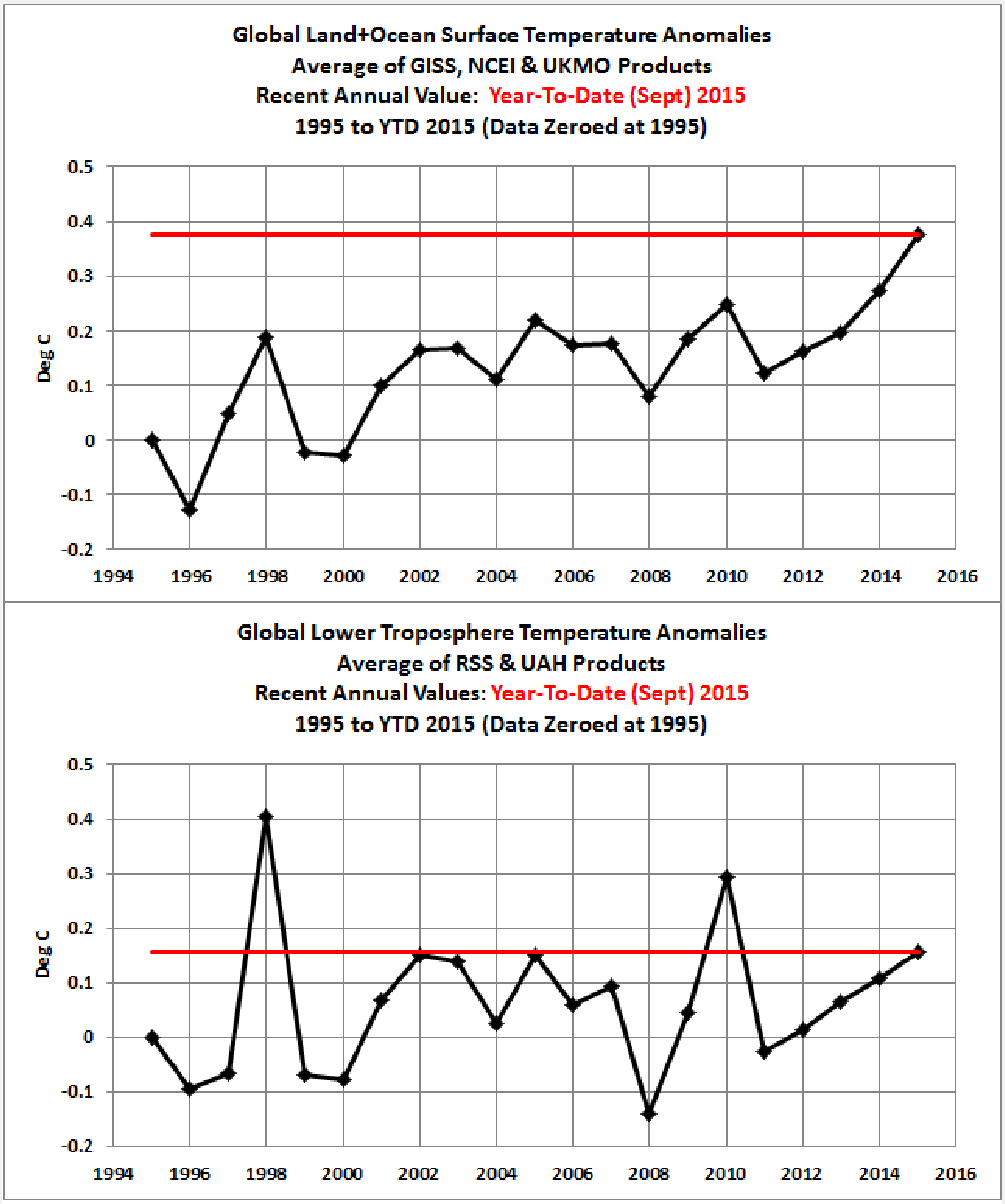


Figure GD-3-3

The surface temperature data includes the average from the three primary suppliers (NASA/GISS, NOAA/NCEI and UKMO). The uptick so far in 2015 will put 2015 at record high levels. On the other hand, the uptick in the average of the RSS and UAH lower troposphere temperature data does not bring the 2015 value anywhere close to the El Niño-caused spikes in 1998 and 2010.

El Niño events typically peak in November to January, evolving in one year and decaying in the next. The very strong 1997/98 El Niño evolved in 1997 and decayed in 1998. So if global surface temperatures were showing only the goings-on in the tropical Pacific, we would expect the spike to appear in 1997 not 1998, but the global surface temperatures peaked in 1998, the decay year. The reason: the global response of surface temperatures outside of the tropical Pacific lag what's happening in the tropical Pacific, so they peak in 1998. You'll note the same lagged effect in 2010 in response to the strong 2009/10 El Niño.

The lagged time response is even more obvious in the lower troposphere temperature data. Lower troposphere temperature anomalies peaked in 1998 in response to the 1997/98 El Niño and peaked in 2010 as a response to the 2009/10 El Niño. That means, for the lower troposphere temperature data, we very well could have another spike in 2016 in response to the 2015/16 El Niño, possibly bringing lower troposphere temperatures to record highs then.

Back to surface temperatures: As discussed in General Discussion 2, The Blob was the primary cause of the record high surface temperatures in 2014. As you will see in this chapter, the persistence of the Blob and the strong El Niño conditions in 2015 are the two primary reasons for the record high surface temperatures this year. Next year, there will lagged effects to the El Niño, so surface temperatures could very well peak in 2016, before dropping once again in 2017 in response to the 2016/17 La Niña, assuming a La Niña follows this El Niño.

LAND SURFACE AIR TEMPERATURES

Year-to-date 2015 data for the three primary suppliers of global land air surface temperature data are included in Figure GD-3-4. All show in uptick this year in response to the El Niño conditions (and possibly due to The Blob). The +0.29 deg C jump in the NOAA/NCEI data appears excessive compared to the +0.20 rise in the UKMO CRUTEM data and the +0.13 deg C uptick in the GISS data. Then again, we're coming to expect the NOAA/NCEI data to show excessing warming.

Note also that land surface air temperature anomalies normally peak in the decay years of the El Niño, which means we should expect to see even higher land surface air temperature anomalies in 2016.

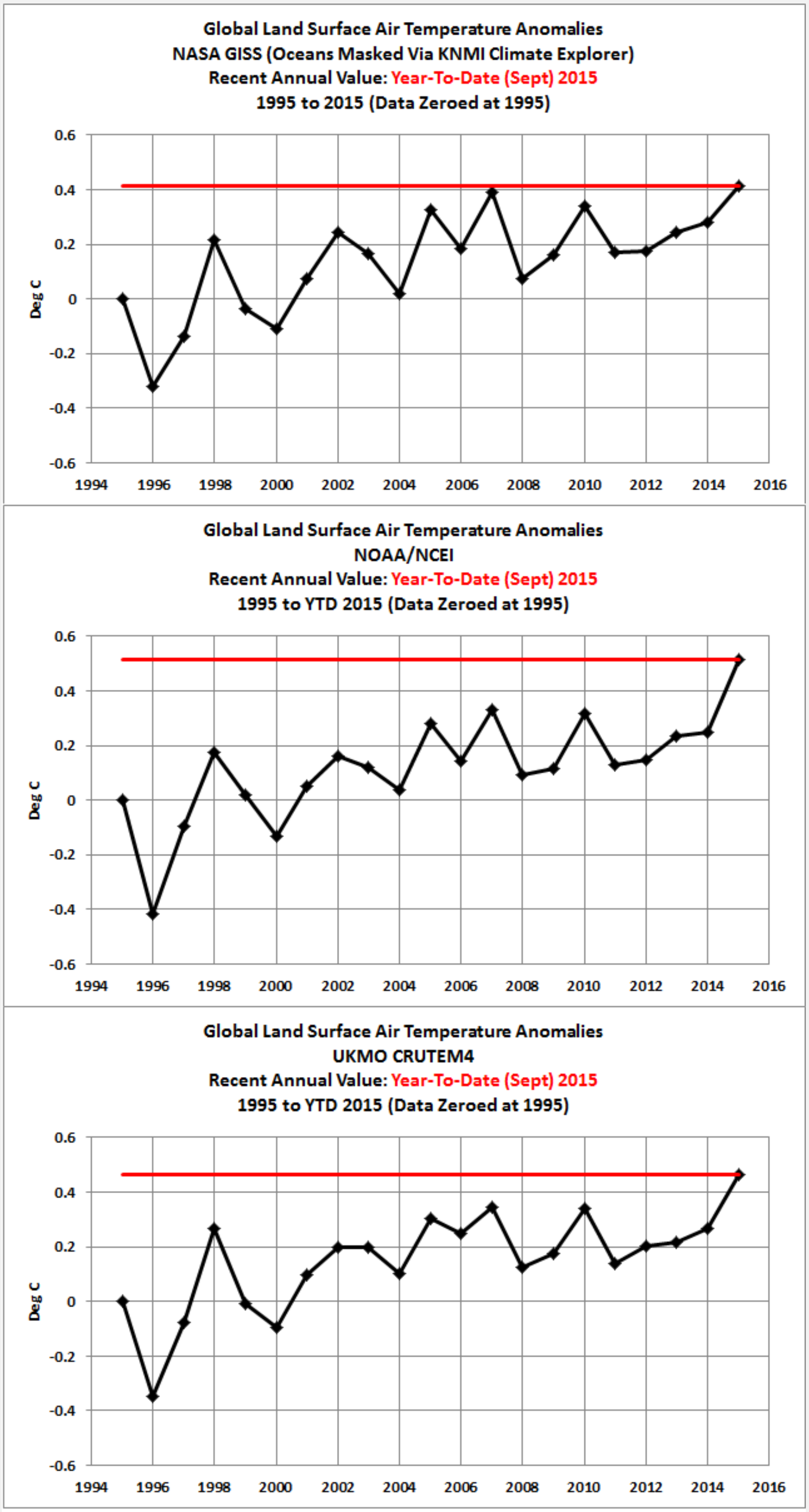

Global Land Surface Air Temperature Anomalies
NASA GISS (Oceans Masked Via KNMI Climate Explorer)
Recent Annual Value: Year-To-Date (Sept) 2015
1995 to 2015 (Data Zeroed at 1995)
Deg C
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
Global Land Surface Air Temperature Anomalies
NOAA/NCEI
Recent Annual Value: Year-To-Date (Sept) 2015
1995 to YTD 2015 (Data Zeroed at 1995)
Deg C
Global Land Surface Air Temperature Anomalies
UKMO CRUTEM4
Recent Annual Value: Year-To-Date (Sept) 2015
1995 to YTD 2015 (Data Zeroed at 1995)
Deg C

Figure GD-3-4

When looking at land surface air temperature data, keep in mind that the warming of land surface air temperature anomalies is primarily a response to the warming of the surface of the oceans. That was the finding of Compo and Sardeshmukh (2009) **Oceanic influences on recent continental warming**. The first sentence of their abstract reads:

> *Evidence is presented that the recent worldwide land warming has occurred largely in response to a worldwide warming of the oceans rather than as a direct response to increasing greenhouse gases (GHGs) over land.*

Now consider that climate models still cannot properly simulate the warming of the oceans or the natural responses of the oceans to coupled ocean-atmosphere processes.

INFO ABOUT THE SEA SURFACE TEMPERATURE DATASET AND CLIMATE MODEL OUTPUTS

As a reminder, I've copied the overview of the Reynolds OI.v2 sea surface temperature datasets from General Discussion 2:

I'm using NOAA's Optimum Interpolation Sea Surface Temperature data (a.k.a. Reynolds OI.v2) for this discussion, because:

- It is the longest running satellite-enhanced sea surface temperature dataset available,
- It's satellite data are bias adjusted based on temperature measurements from ship inlets and from buoys (both moored and drifting), and
- Most importantly, NOAA's Reynolds OI.v2 data have been called "a good estimate of the truth". See Smith and Reynolds (2004) Improved Extended Reconstruction of SST (1854-1997). The authors stated about the Reynolds OI.v2 data (my boldface):

  > *Although the NOAA OI analysis contains some noise due to its use of different data types and bias corrections for satellite data,* ***it is dominated by satellite data and gives a good estimate of the truth****.*

Additional notes about my choice of sea surface temperature datasets:

- Though satellite data are not included in the new NOAA ERSST.v4 data, Reynolds OI.v2 data are used for quality control of the new ERSST.v4 dataset. See the post Quick Look at the DATA for the New NOAA Sea Surface Temperature Dataset.
- Along with HADISST data, Reynolds had been used (past tense) in the GISS Land-Ocean Temperature Index data until early in 2013, but GISS switched to

NOAA's ERSST.v3b data to bring their long-term trends into line with the NCDC and HADCRUT datasets. During the satellite era, the change from Reynolds OI.v2 to ERSST.v3b data had little impact. See the post A Look at the New (and Improved?) GISS Land-Ocean Temperature Index Data. Reynolds OI.v2 data (along with HADISST) are still available for presentations at the GISS Map-Making Webpage and for download by researchers.

- Reynolds OI.v2 data are also used in a number of reanalyses, including CMCC C-GLORS, ECMWF ORAS4, ECMWF ORAS3, GFDL, GLORYS2V1, GMAO and NCEP/GODAS. See the Reanalysis.org webpage Overview of current ocean reanalyses.

The Reynolds OI.v2 sea surface temperature data presented in this discussion are from the KNMI Climate Explorer…as are the model simulations of sea surface temperatures.

The climate models presented in this post are those stored in the CMIP5 archive, which was used by the IPCC for their 5th Assessment Report (AR5). The CMIP5 climate model outputs of sea surface temperature are available through the KNMI Climate Explorer, specifically through their Monthly CMIP5 scenario runs webpage, under the heading of Ocean, ice and upper air variables. Sea surface temperature is identified as "TOS" (temperature ocean surface). I've used the simulations with the historic and RCP8.5 forcings.

Back to the discussion of global sea surface temperatures:

GLOBAL SEA SURFACE TEMPERATURES WERE AT RECORD HIGHS IN 2014 AND THEY'RE EVEN HIGHER IN 2015

But those record high sea surface temperatures in 2015 are not surprising with the impacts of The Blob and the strong El Niño conditions

As discussed in General Discussion 2, I've presented the global sea surface temperature data two ways in Figure GD-3-5, with and without the polar oceans. The suppliers of global land+ocean surface temperature data (GISS, NCEI, and UKMO) treat the polar oceans differently, so I've shown the data two ways. (We'll discuss those differences between the data suppliers in more detail in part 2 of this book.) Because the surface area of the Southern Ocean surrounding Antarctica (about 22 million km^2) is greater than that of the Arctic Ocean (about 16 million km^2), the cooling taking place on the surface of the Southern Ocean outweighs the warming taking place on the surface of the Arctic Ocean. That's why the data with the polar oceans shows slightly less warming in Figure GD-3-5 than the data that excludes them. That, of course, was another reason I presented global sea surface temperature data with and without the polar oceans…to show you that basic reality.

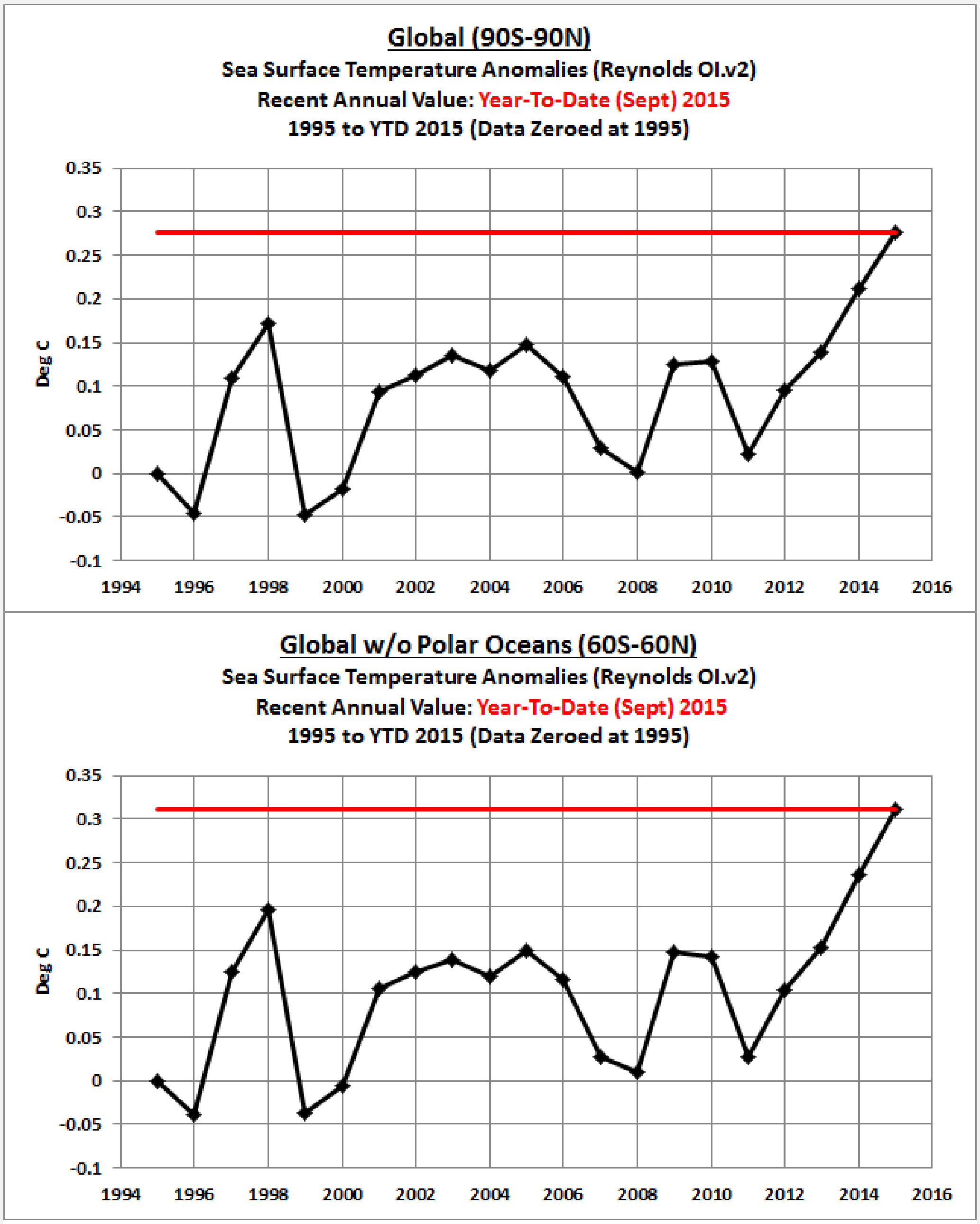


Figure GD-3-5

SEA SURFACE TEMPERATURES: EAST PACIFIC VERSUS THE REST OF THE GLOBAL OCEANS

Before we illustrate the sea surface temperature anomalies for the individual ocean basins, we're going to divide ocean surface data into two subsets. See the map in Figure GD-3-6. Just looking at the map, you can understand why I've divided the data this way.

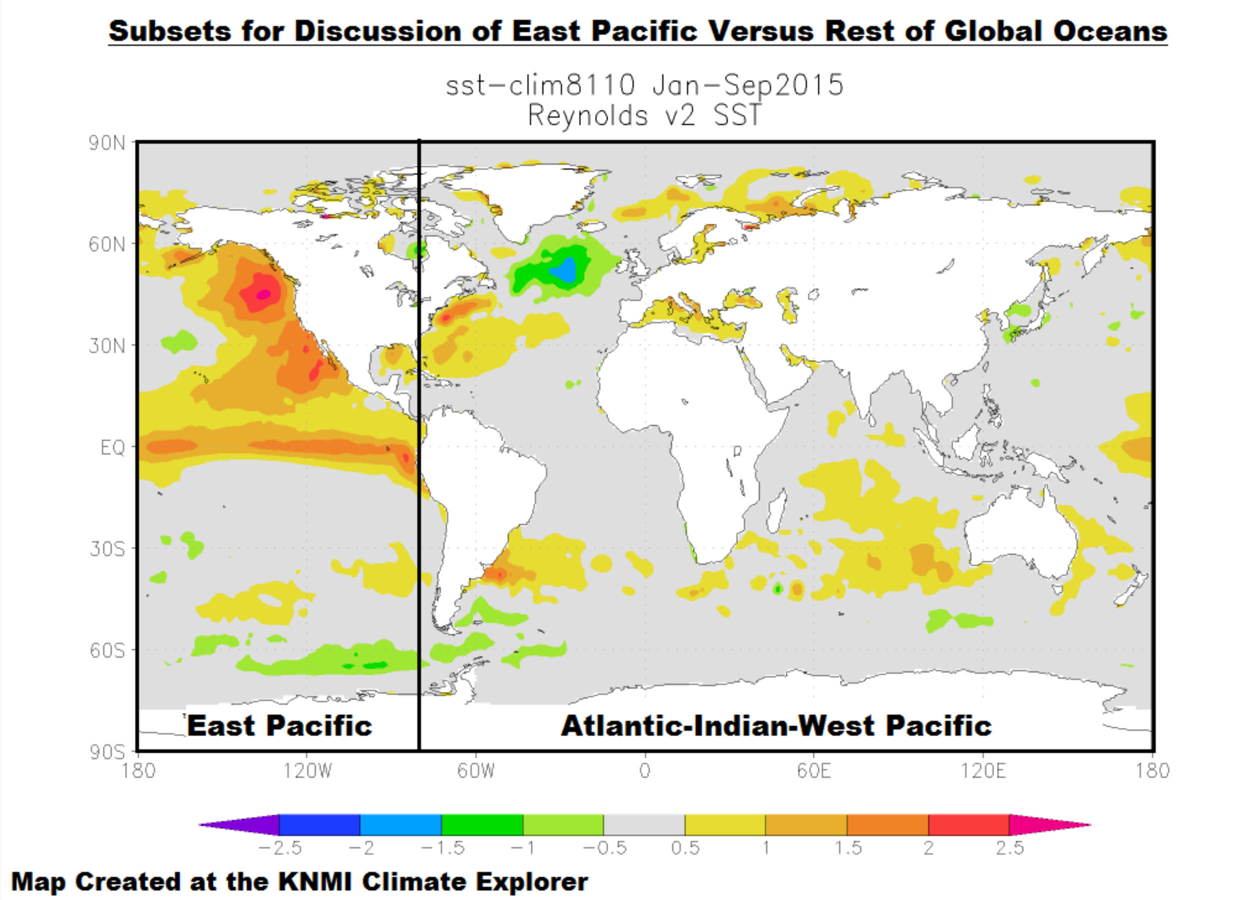


Figure GD-3-6

The highest sea surface temperature anomalies are in the East Pacific Ocean, primarily the Eastern North Pacific. We can see The Blob and the Baja Hotspot, which is likely an aftereffect of The Blob (and possibly an aftereffect of El Niño processes), along with the elevated sea surface temperature anomalies along the eastern equatorial Pacific caused by the strong El Niño conditions.

Figure GD-3-7 presents the annual times series data for those two regions, starting in 1995 and zeroed there. Once again, the 2015 values are the averages of the January to September data. Also note that the data include their respective portions of the polar oceans.

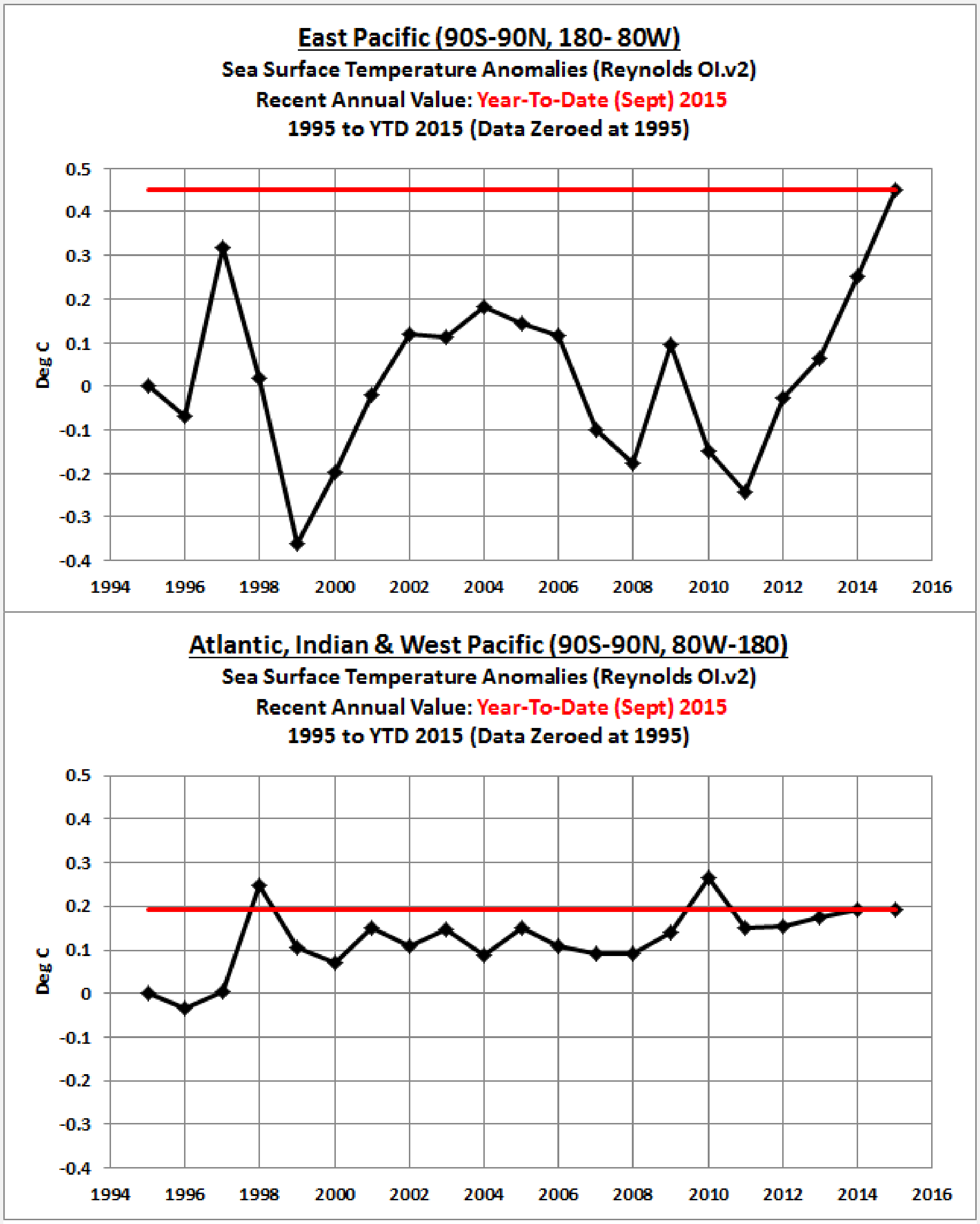


Figure GD-3-7

It's obvious that the East Pacific is responsible for the record high global sea surface temperatures in 2015. Sea surface temperatures for the Atlantic-Indian-West Pacific subset were higher in 1998 and 2010 than in 2015. 1998 and 2010 are the decay years of the 1997/98 and 2009/10 El Niños.

Something else stands out in those two graphs. We can see the drops in East Pacific sea surface temperature in response to the La Niña events that follow the strong El Niños, but the Atlantic-Indian-West Pacific data to not show proportional declines in sea surface temperatures in response to the La Niñas. There are very basic reasons for this and we'll discuss them in detail in Chapter 3.7 – Ocean Mode: El Niño and La Niña.

INDIVIDUAL OCEAN BASINS

These are updates of the graphs presented in General Discussion 2. Let's start with North and South Atlantic data. See Figure GD-3-8.

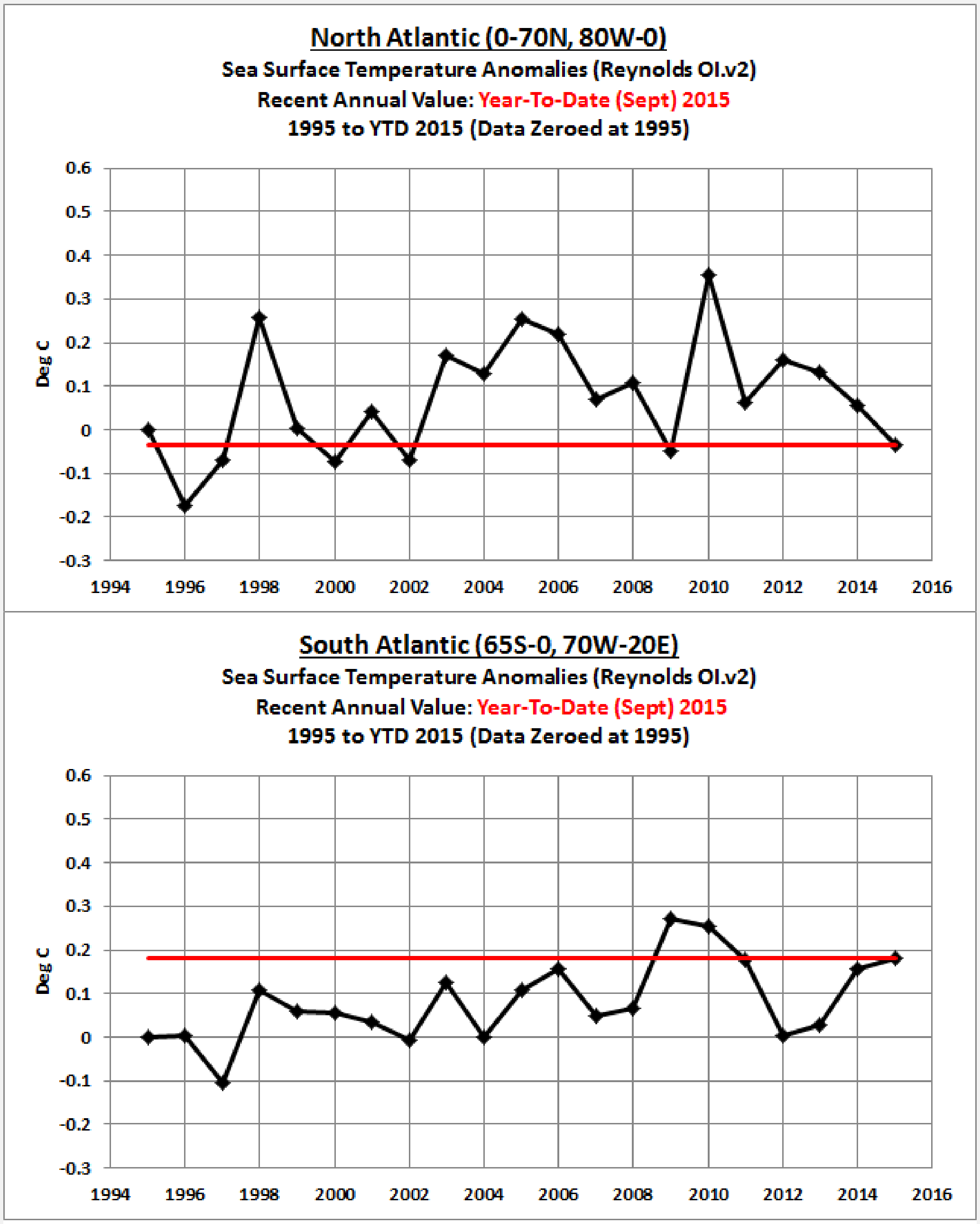


Figure GD-3-8

The North Atlantic cooled slightly in 2015, while the South Pacific warmed a tick, but in both cases sea surface temperatures were not near record highs. We should expect an uptick in the North Atlantic next year, though.

Next are the polar oceans, Figure GD-3-9. So far in 2015, the Arctic sea surface temperatures are basically tied for (but not at) record-high levels. Then again, the Southern Ocean is once again showing record lows.

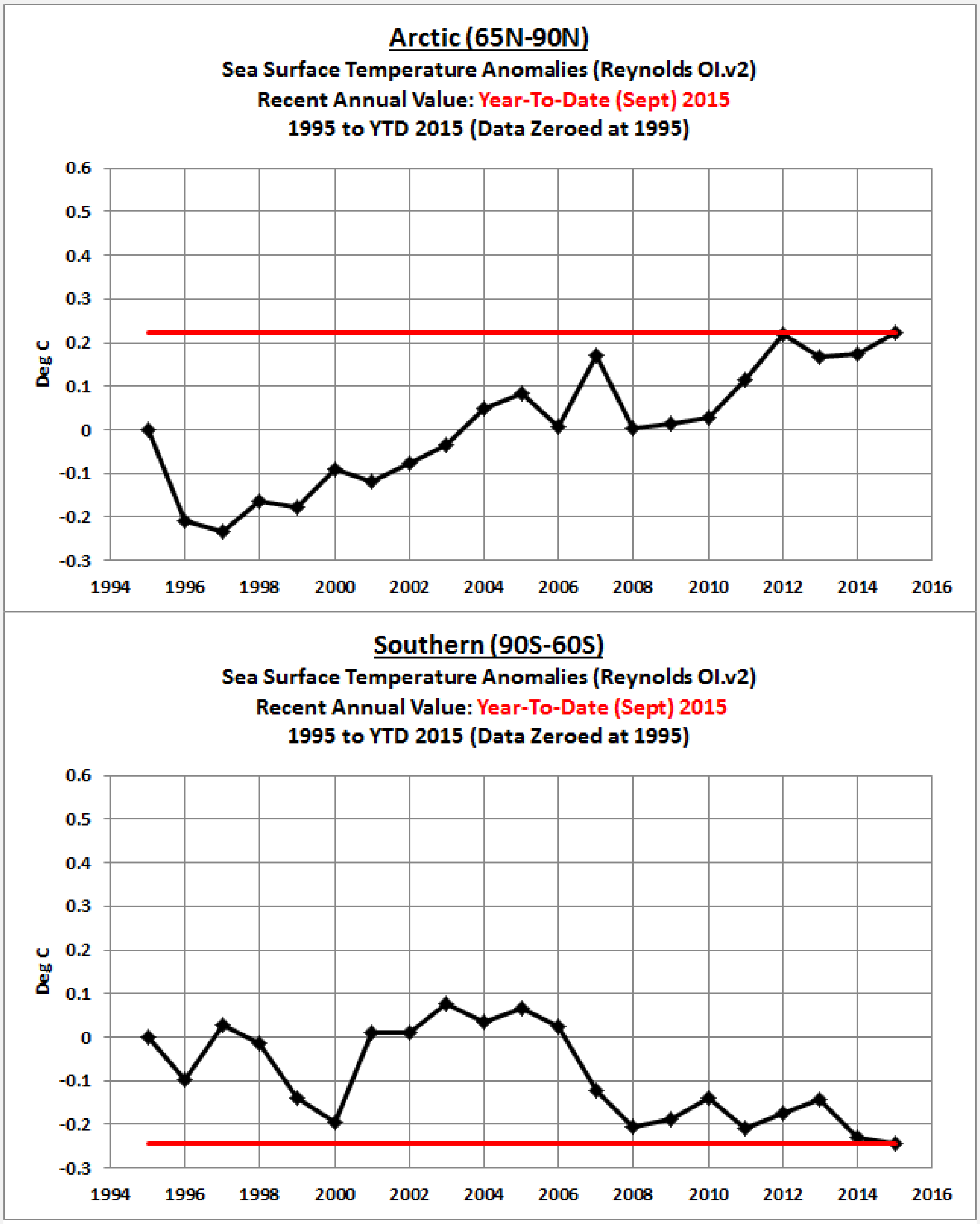


Figure GD-3-9

The sea surface temperature data for the Indian and South Pacific oceans are shown in Figure GD-3-10. For those two subsets, sea surface temperatures so far in 2015 are basically tied with earlier years, but not at record highs.

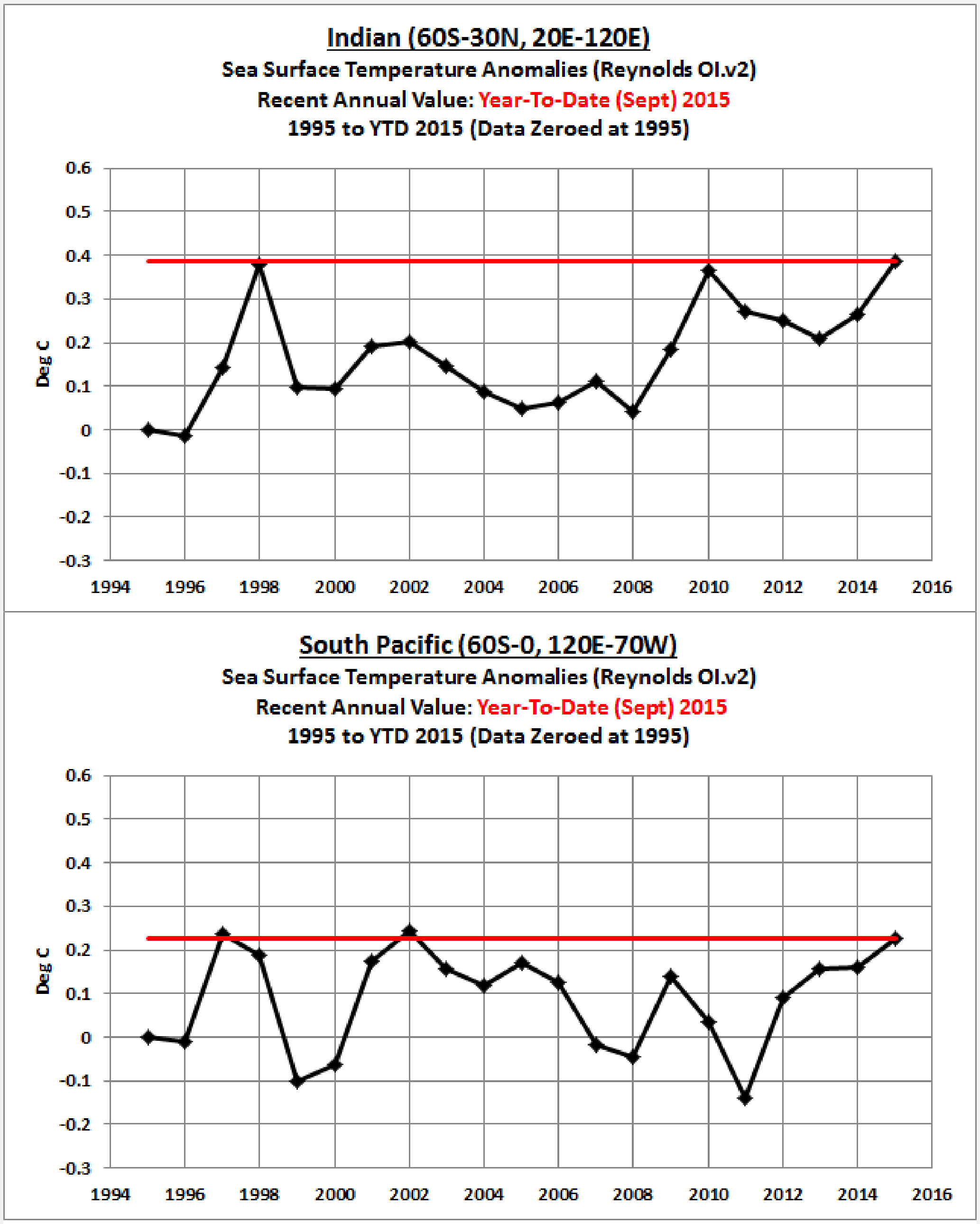


Figure GD-3-10

NORTH PACIFIC

It was easy to tell in the map of year-to-date sea surface temperature anomalies, Figure GD-3-6, that the North Pacific was going to show very obvious record highs, and they stand out plainly in Figure GD-3-11.

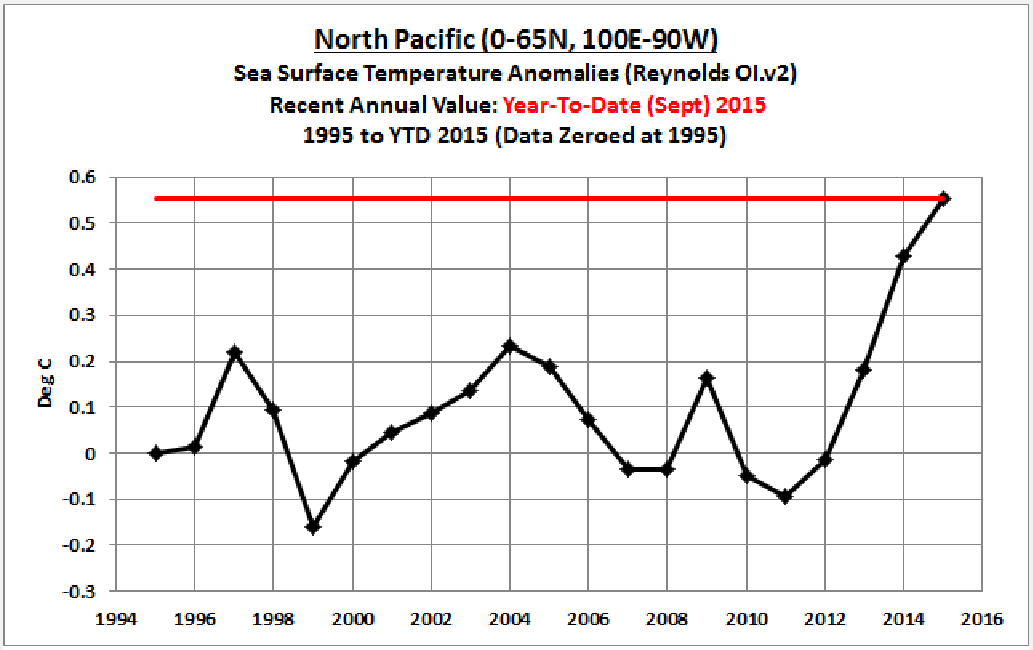


Figure GD-3-11

And looking at the North Pacific sea surface temperature data divided at the dateline, Figure GD-3-12, we can see that the high sea surface temperatures were confined to the eastern North Pacific, not the western portion.

So, once again, it's the eastern North Pacific that's primarily responsible for the record-high global sea surface temperatures in 2015.

Notice how the sea surface temperatures of the western North Pacific (top graph of Figure GD-3-12) rose in 1998 in a lagged response to the 1997/98 El Niño…and then basically stayed there at those elevated levels. We can also see something similar in the Indian Ocean data (top graph of Figure GD-3-10), a stair-like effect. There are very basic El Niño processes that cause those upward shifts, and we'll discuss them in great detail in Chapter 3.7 – Ocean Mode: El Niño and La Niña. We may expect another upward shift as an aftereffect of the 2015/16 El Niño…and The Blob. Warm water from an El Niño in the East Pacific doesn't simply disappear when the El Niño is over. That El Niño-related warm water is relocated to other portions of the global oceans.

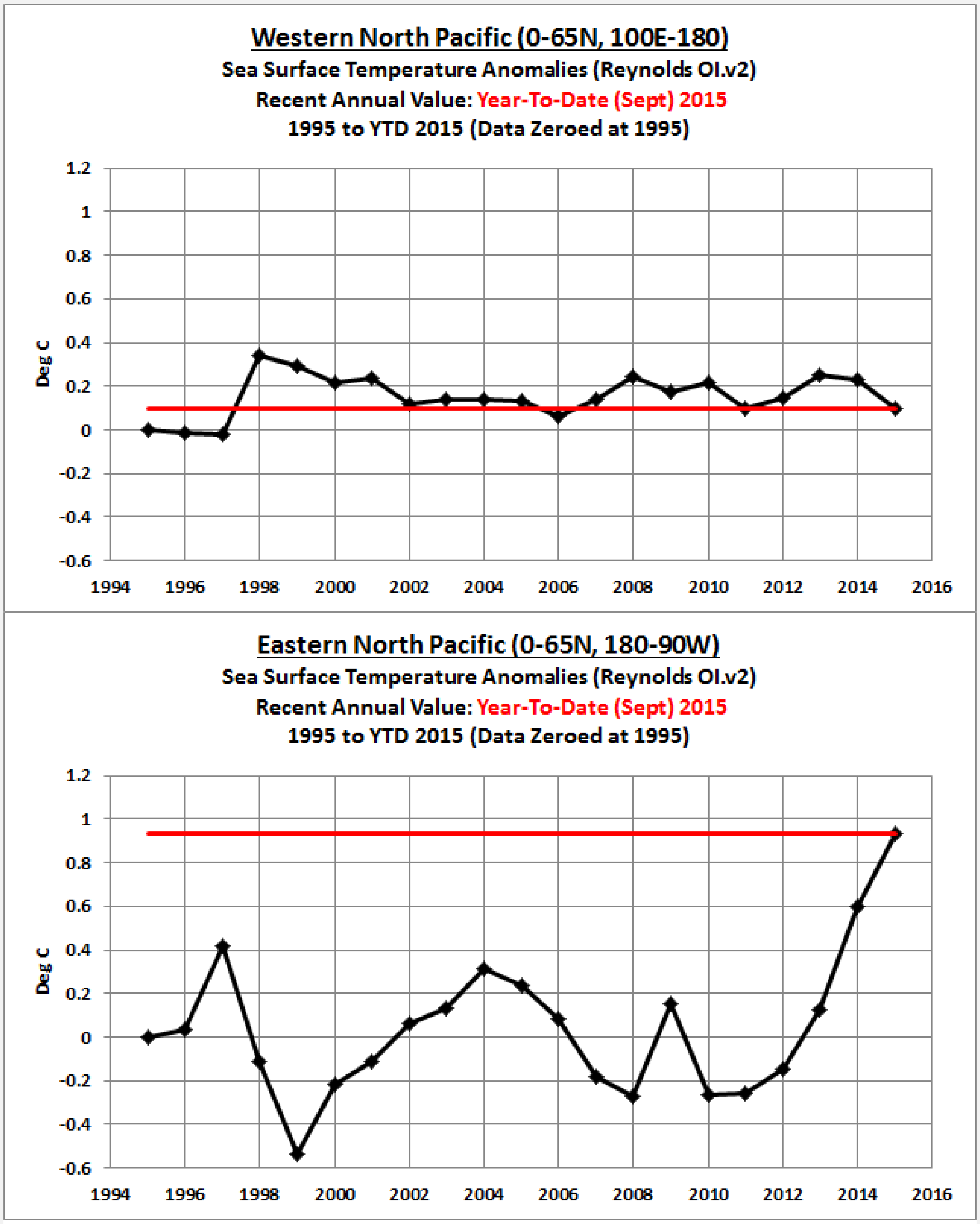


Figure GD-3-12

UPDATES OF MODEL-DATA COMPARISONS FOR THE PACIFIC AND ITS SUBSETS

In General Discussion 2, we compared sea surface temperature anomalies for the Eastern North Pacific, the North Pacific and the Pacific Ocean as a whole to the climate model simulations of the sea surface temperatures for those three regions. The updates in Figures GD-3-13 through GD-3-15 are included as the bottom graphs. They include the comparisons with year-to-date (September) 2015 values added. The top graphs are for the 19-year period of 1995 to 2013. They serve as a reminder that the surface of the Pacific and the two subsets had shown no warming for 19 years prior to The Blob in 2014…and the El Niño and the continuation of The Blob in 2015. Let's start with the Eastern North Pacific, Figure GD-3-13.

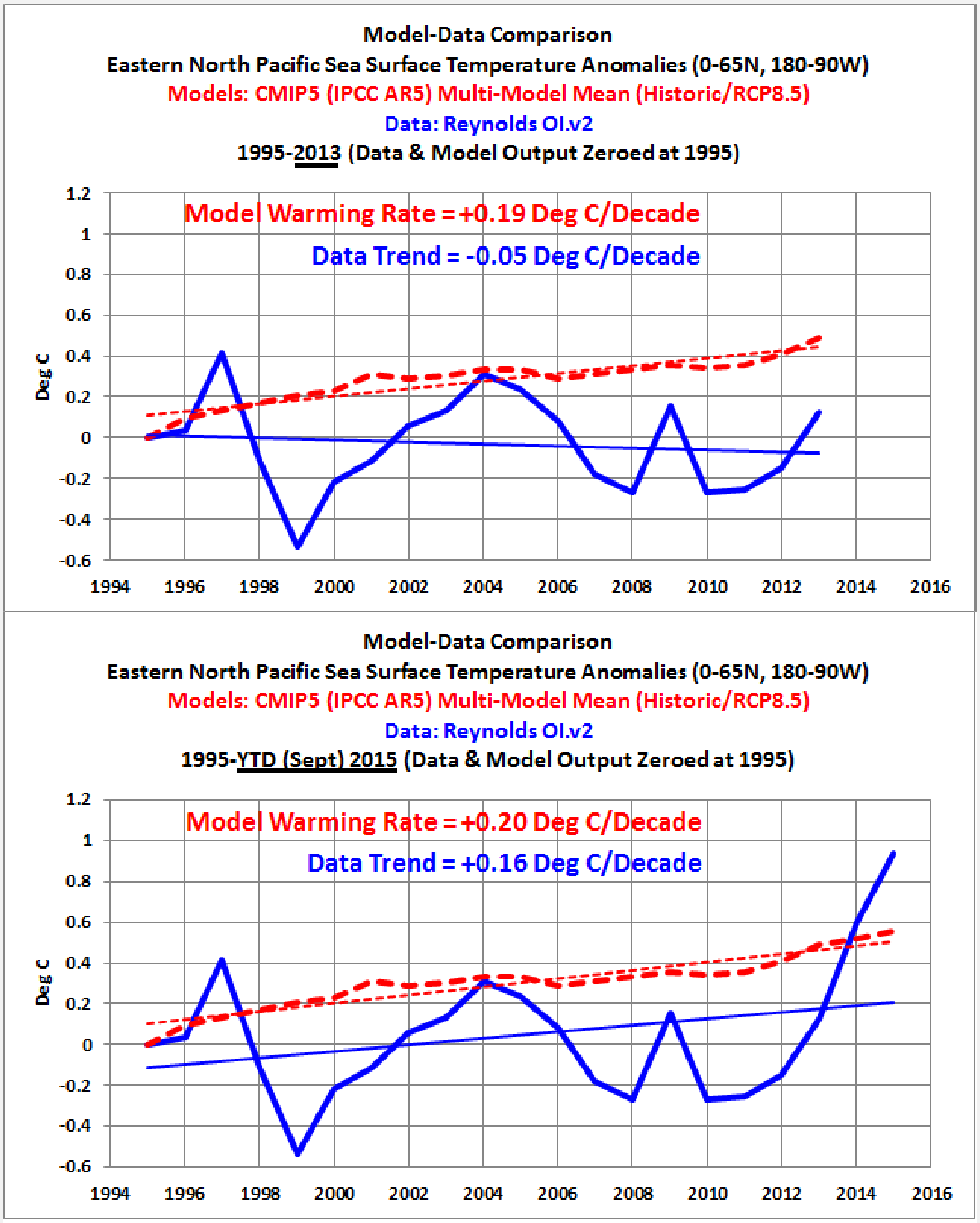


Figure GD-3-13

As shown in Figure GD-3-13, the surface of the Eastern North Pacific had shown no warming for 19 years, creating a large disparity between models and data. Then, with the impacts of the unusual natural warming event known as The Blob in 2014 and 2015, and with the natural effects of the El Niño in 2015, the model-data difference has evaporated in the Eastern North Pacific. And now, alarmists are blaming mankind's emissions of greenhouse gases for the warming there even though that warming occurred naturally. Luckily, if a La Niña forms in 2016, there should be a drop in the sea surface temperatures. How much the sea surface temperatures drop in 2016 will depend on the strength of the La Niña and what The Blob decides to do.

Next in Figure GD-3-14 are the comparison graphs for the North Pacific.

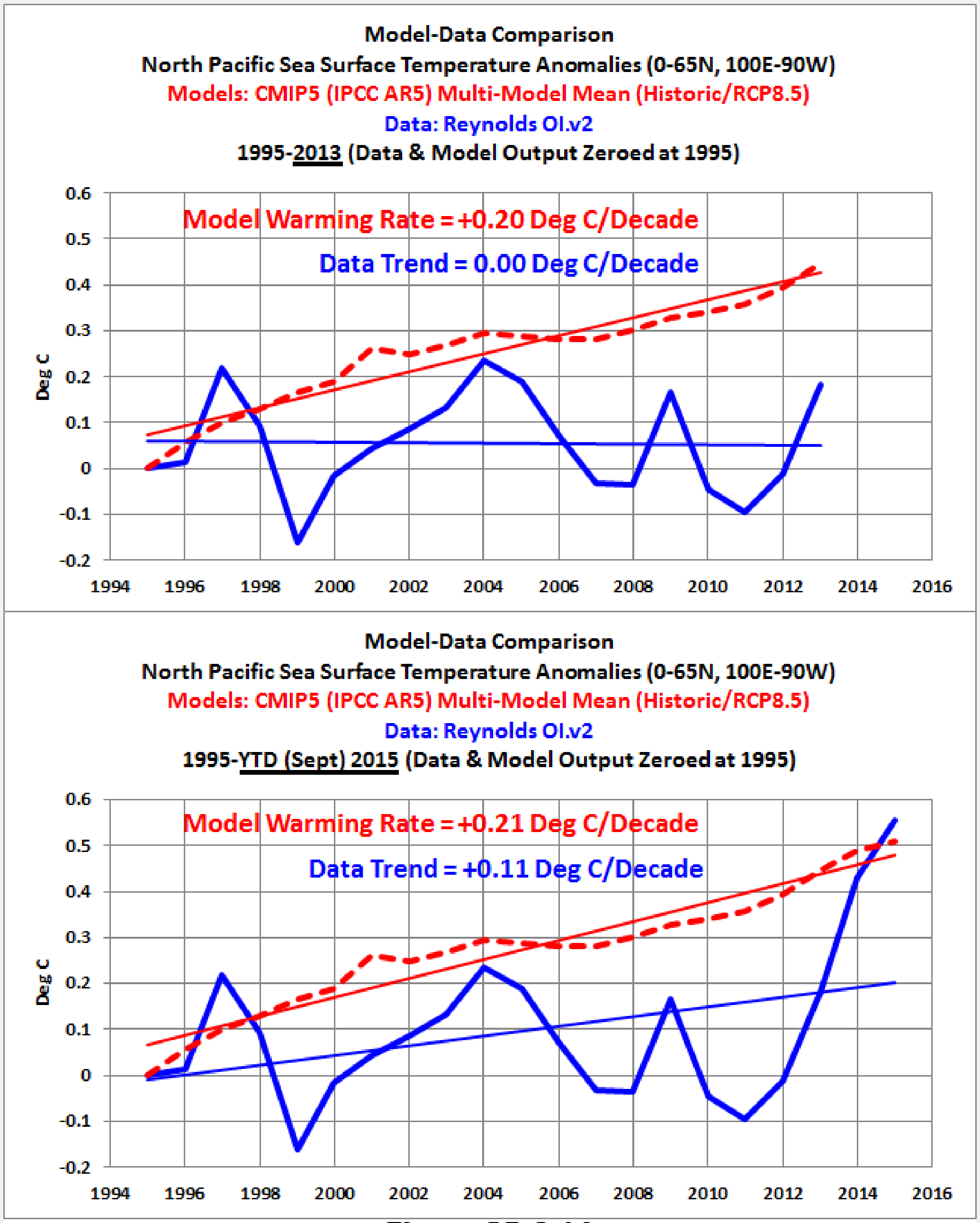


Figure GD-3-14

The Blob in 2014 and 2015 and 2015/16 El Niño created a naturally caused warming trend in the North Pacific, when none had existed for the 19-year period from 1995 to

2013. However, that warming rate still falls far short of rate shown by the model mean, which represents the groupthink for how the North Pacific should have warmed if its warming was dictated by man-made greenhouse gases.

Last under this heading is the Pacific Ocean as a whole, Figure GD-3-15.

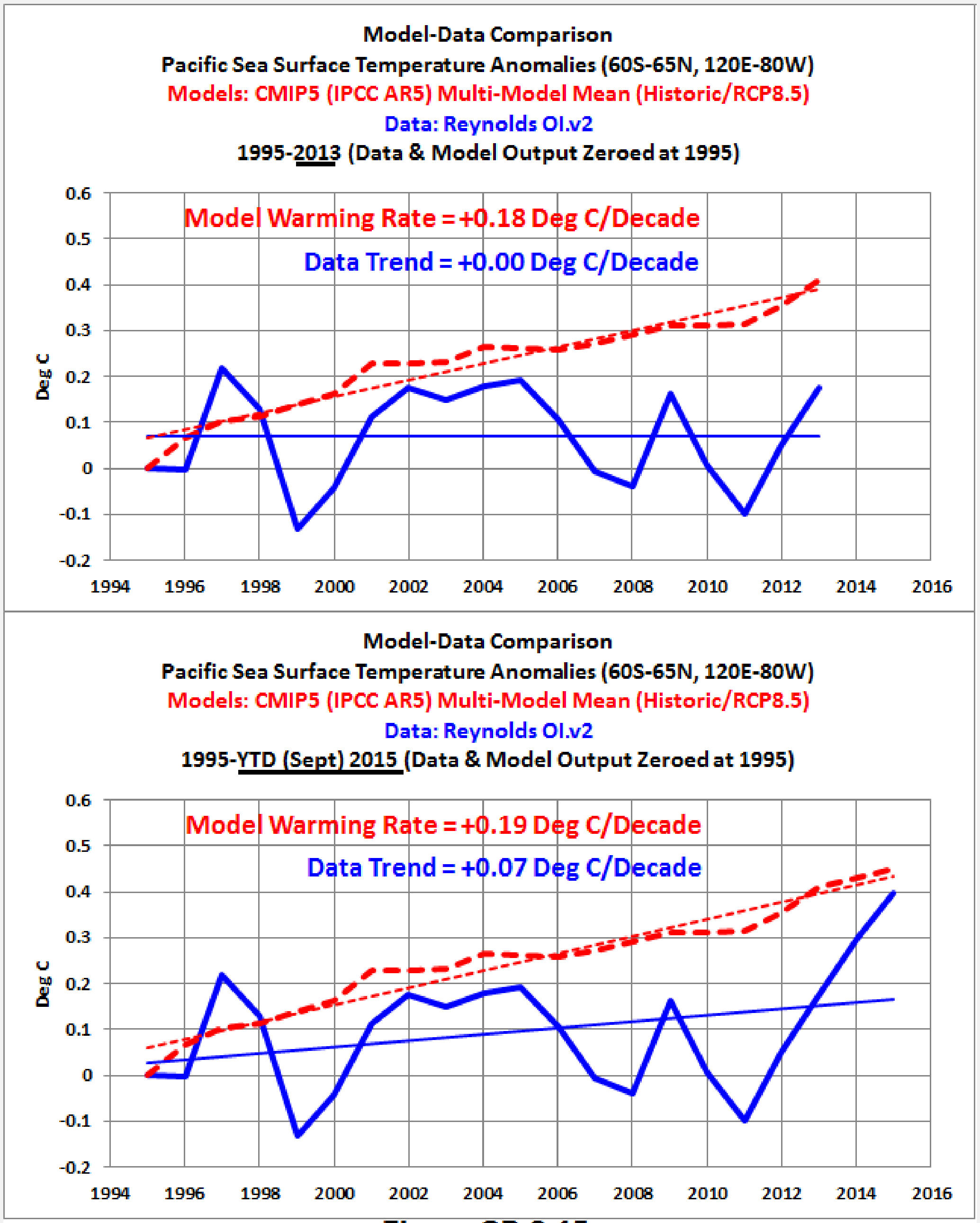
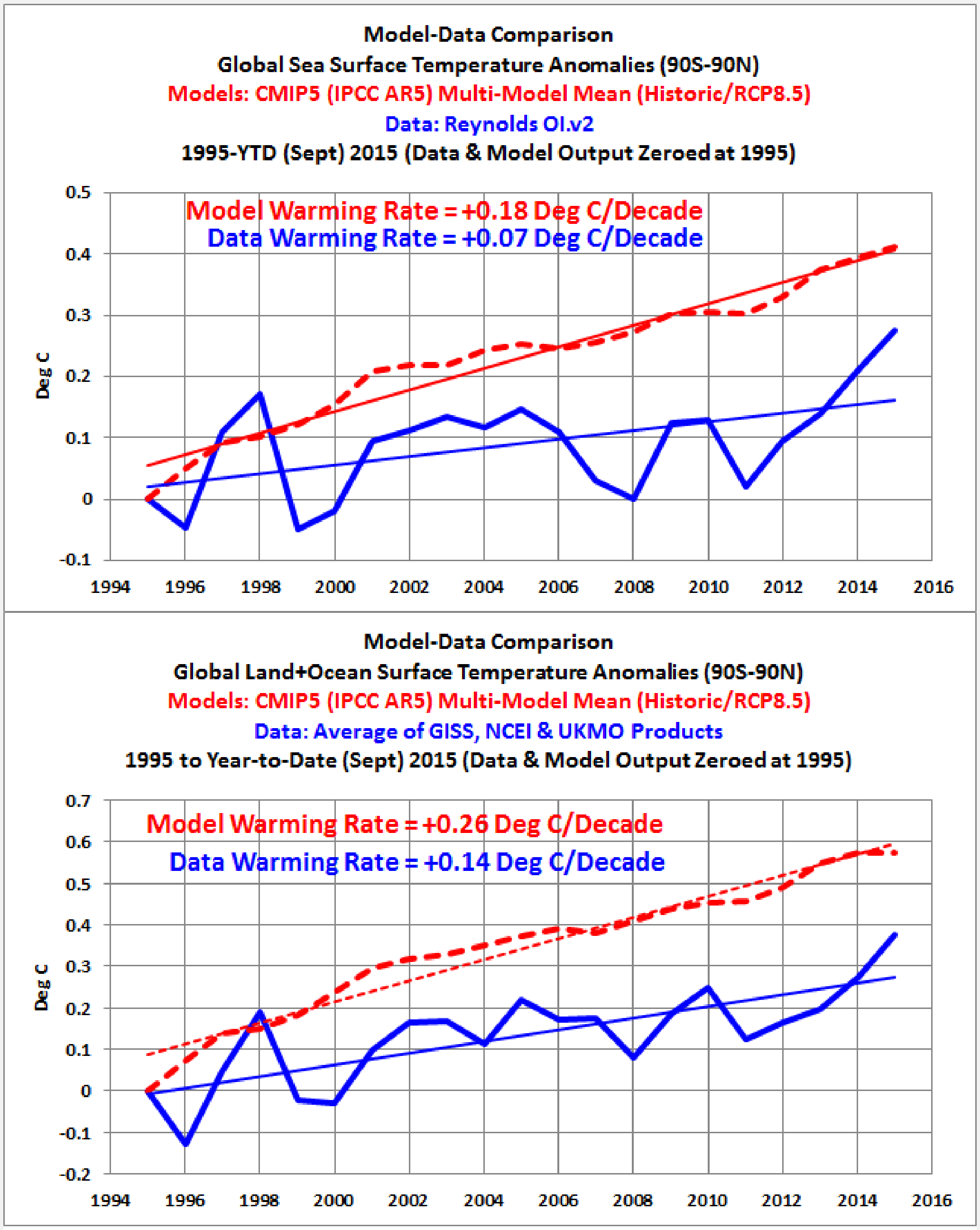


Figure GD-3-15

Even with the natural warming associated with the El Niño and The Blob, the models more than double the warming rate of the Pacific Ocean when we include the data through year-to-date (September) 2015.

The 2016/17 La Niña, assuming one forms, will lower the trends somewhat. But even if the Blob were to disappear in 2016 and even if sea surface temperature anomalies were to return to the values they were at prior to The Blob, The Blob will have impacted the long-term warming of the Eastern North Pacific, the North Pacific and the Pacific Ocean as a whole.

SUMMARY



Note The Different Temperature Ranges

Figure GD-3-16

The strong El Niño conditions in 2015 and The Blob in 2014 and 2015 (both of which are naturally occurring events) were the primary causes of the global warming we experienced in 2014 and 2015. Both created noticeable upticks in global sea surface temperatures and in global land+ocean surface temperatures. While those upticks did increase the observed warming rates of global surface temperatures, as shown in Figure GD-3-16, the models still more than double the warming rate of the surfaces of the global oceans and almost double the observed warming rate of the combined land+ocean surfaces.

3 – NATURAL VARIABILITY

Global surface temperatures and climate in general are always changing. They have changed in the past and will continue to change in the future. In addition to the hypothetical impacts of man-made greenhouse gases, there are numerous naturally occurring atmospheric and oceanic processes that cause global surface temperatures and climate to vary. However, before we present them, we need to discuss atmospheric and ocean circulations. We'll begin with atmospheric circulation, move on into ocean circulation, which is dependent in part on atmospheric circulation, and then discuss the naturally occurring variability of the atmosphere and ocean. The oceans and atmosphere are of course coupled, meaning variations in ocean conditions impact the atmosphere above them, and atmospheric circulation also impacts the surfaces of the oceans.

As a result of that coupling between oceans and atmosphere, you'll find that when we discuss the ocean modes of natural variability, such as the Atlantic Multidecadal Oscillation and El Niño & La Niña events, we also discuss the changes in atmospheric circulation associated with them.

3.1 – Introduction to Atmospheric Circulation

This chapter provides a very brief introduction to atmospheric circulation. There are a number of excellent, very detailed, introductory presentations of these basic processes around the web. There are links to a few of them at the end of this chapter. Please understand that the latitudes discussed in this chapter are generalities, and that they vary considerably over the course of a year with the seasons and with weather patterns in general…weather is always changing.

The Wikipedia webpage on Atmospheric Circulation provides a simple, easy-to-understand opening definition:

> ***Atmospheric circulation*** *is the large-scale movement of air, and the means (together with the smaller ocean circulation) by which thermal energy is distributed on the surface of the Earth.*

North Carolina State University also has a nice introductory statement on their General Circulation of the Atmosphere webpage, which is part of their Climate Education for K-12 series. They write:

> *The circulation of wind in the atmosphere is driven by the rotation of the earth and the incoming energy from the sun. Wind circulates in each hemisphere in*

> *three distinct cells which help transport energy and heat from the equator to the poles. The winds are driven by the energy from the sun at the surface as warm air rises and colder air sinks.*

Those are three very important statements.

We'll discuss atmospheric circulation in great detail throughout this chapter, but the take-home message from that introductory statement is that atmospheric circulation is driven by the energy from the Sun and by the rotation of the Earth.

CONVECTION

Convection is term used by meteorologists and climate scientists that refers primarily to the movement of the air in the atmosphere in a vertical direction.

Sunlight warms the surfaces of the planet. Some surfaces warm more quickly than others. Often times, convection occurs where the surface warms rapidly. There, the sun-warmed surface heats the air directly above it. That warmed air becomes less dense than the air above, so the warmed air rises. That column of upward air movement is called a thermal. Those thermals carry moisture as they travel higher into the atmosphere, and because the air is colder at higher altitudes, the moisture in the air condenses and forms clouds. When the moisture condenses, turning from a gaseous to liquid state, it releases heat in a process called latent heating. (Latent heat is the heat released or absorbed by a substance during a change in its physical state, without a change in its temperature.)

THE SUN WARMS THE PLANET MORE IN THE TROPICS THAN AT THE POLES

In primary school, we learned that sunlight is more intense in the tropics than it is at the poles, and as a result, the tropics are warmer than the Arctic and Antarctica. Let's confirm that, and also show that the air in the tropics holds more moisture.

Basically, over the course of a year, the same amount of sunlight is spread over a larger area at the poles than in the tropics. See Figure 3.1-1. Phrased another way, the sunlight is more concentrated at the equator than at the poles.

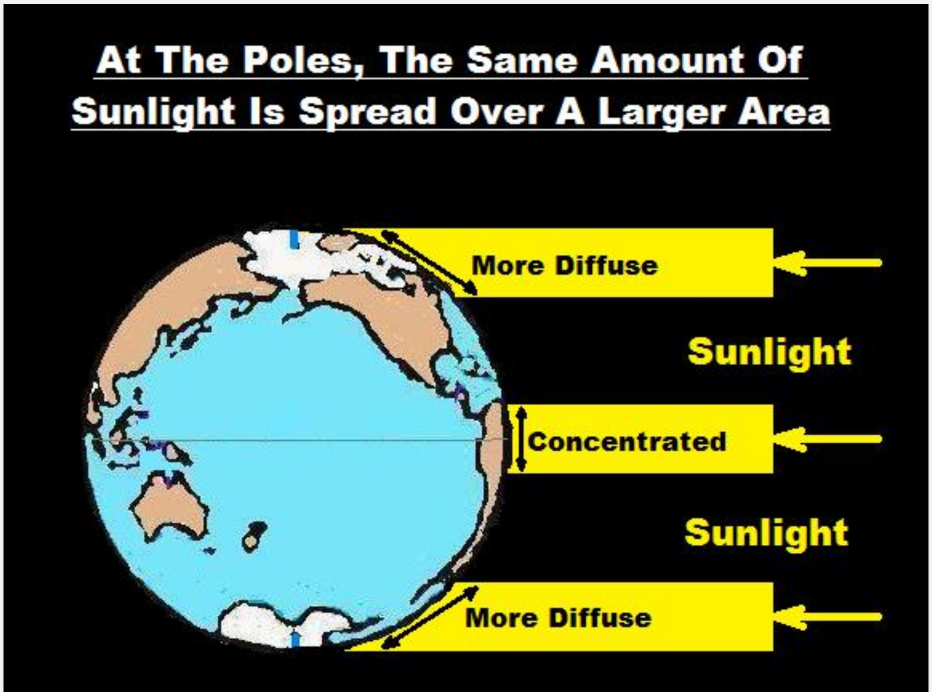


Figure 3.1-1

We can confirm the intensities with outputs from the NCEP-DOE Reanalysis-2. (That reanalysis is no longer available in easy-to-use form online. Sorry.)

Figure 3.1-2 presents the average annual downward shortwave radiation (sunlight) at the surface (maroon curve) and at the top of the atmosphere (orange curve) for the period of 1981-2010, on a latitude-average basis. The units of the vertical axis (y-axis) are watts per square meter (watts/m^2), with the area in square meters referring to the surface, not the top of the atmosphere. And the horizontal axis (x-axis) is longitude, with the South Pole to the left, the North Pole to the right and the Equator in the center at 0 degrees longitude.

As illustrated, the amount of sunlight reaching the top of the atmosphere is much greater in the tropics than at high latitudes. Clouds and aerosols reflect much of the sunlight, preventing much of the sunlight from reaching Earth's surface. We can see that as the difference between the downward shortwave radiation at the surface and at the top of the atmosphere. The dip in the downward shortwave radiation at the surface, that's just north of the equator, results from increased cloud cover there, a region called the Inter-Tropical Convergence Zone (ITCZ).

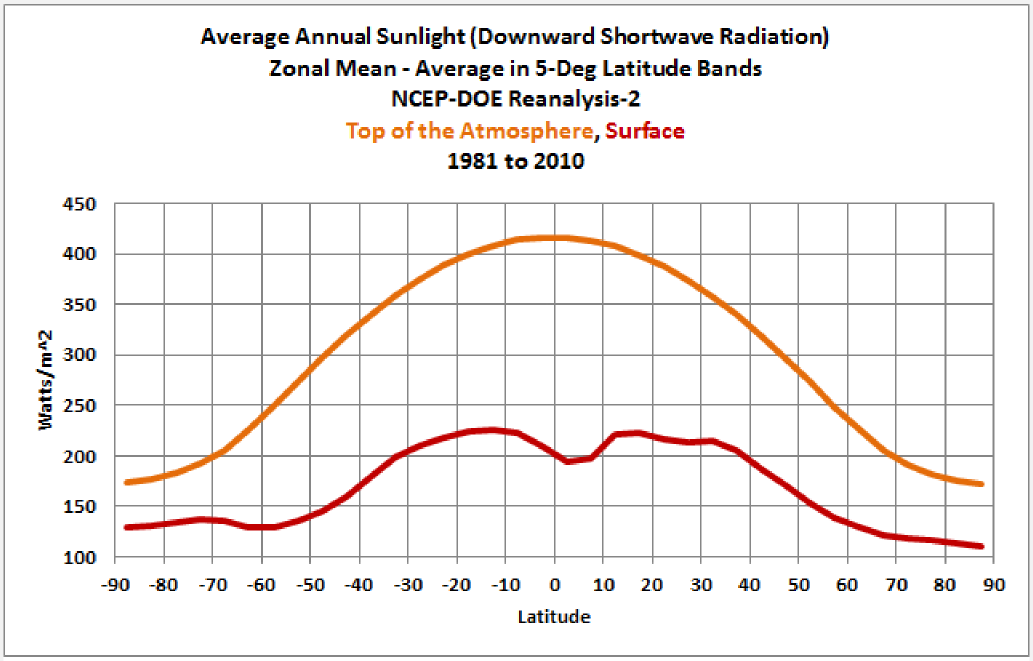


Figure 3.1-2

Because the sunlight is more concentrated in the tropics than at the poles, the surface temperatures of the tropics are in turn much warmer than they are at high latitudes. And we can confirm this with a graph that presents the average sea surface temperatures and land surface air temperatures for the period of 1981-2010, also on a latitude-average basis. See Figure 3.1-3. Because the three primary suppliers of land surface air temperature data (GISS, NCDC and UKMO) only furnish their data in anomaly form, we have to use the output of a reanalysis called GHCN-CAMS. The sea surface temperature data shown is the HADISST data from the UKMO. Both are available through the KNMI Climate Explorer.

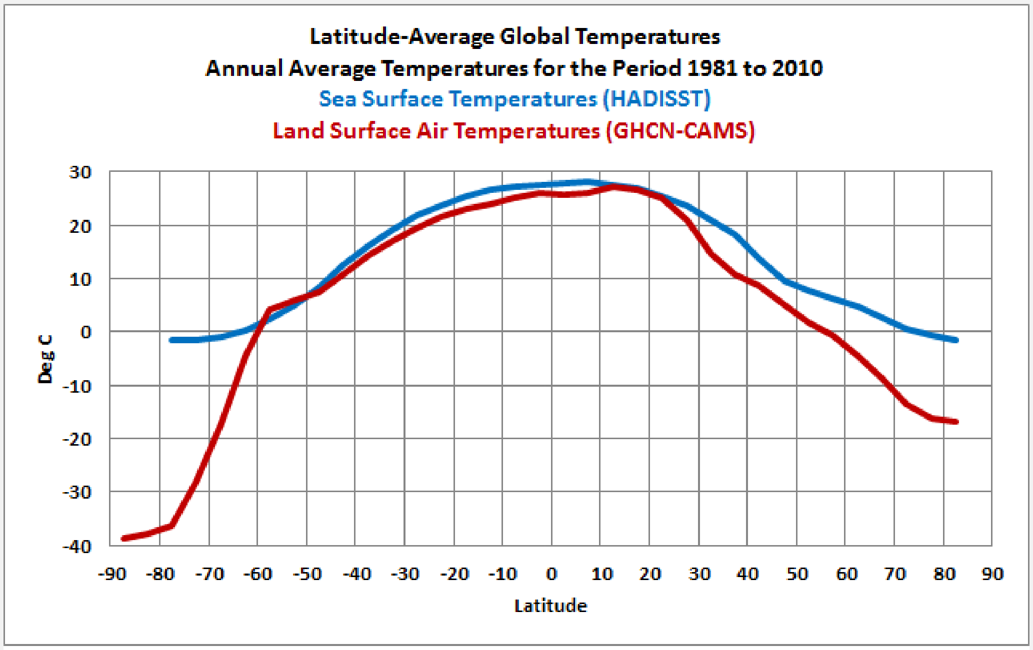


Figure 3.1-3

At most latitudes, the average annual sea surface temperatures are warmer than land surface air temperatures. It must be kept in mind: the sea surface temperature data do not represent the surface temperatures of sea ice in the Arctic Ocean and in the Southern Ocean surrounding Antarctica. Sea surface temperature data can only reach as low as the freezing temperature of ocean water.

One thing is certain: at the surface, it's warmer in the tropics than at the poles.

The atmosphere immediately above the surface, at the level known as the lower troposphere, is also much warmer in the tropics than at the poles. Remote Sensing Systems (RSS) furnishes their lower troposphere temperature data in absolute and anomaly forms, and both are available through the KNMI Climate Explorer. See Figure 3.1-4, which presents the average annual RSS lower troposphere temperature data in absolute form, for the period of 1981-2010, on a latitude-average basis. RSS excludes the lower troposphere data above Antarctica due to the high altitudes of that continent.

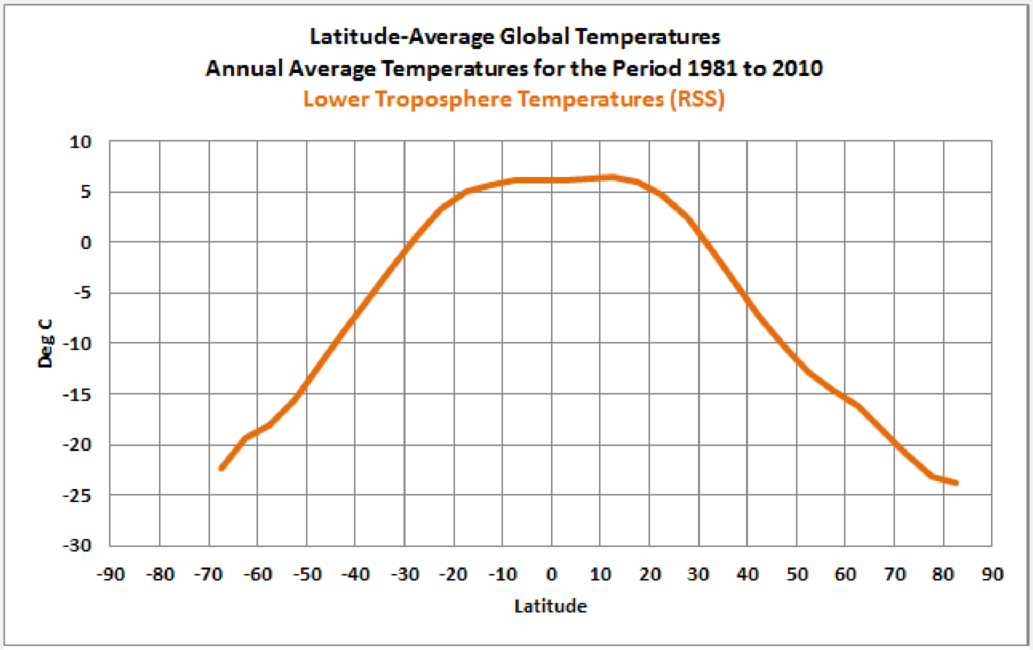


Figure 3.1-4

# # #

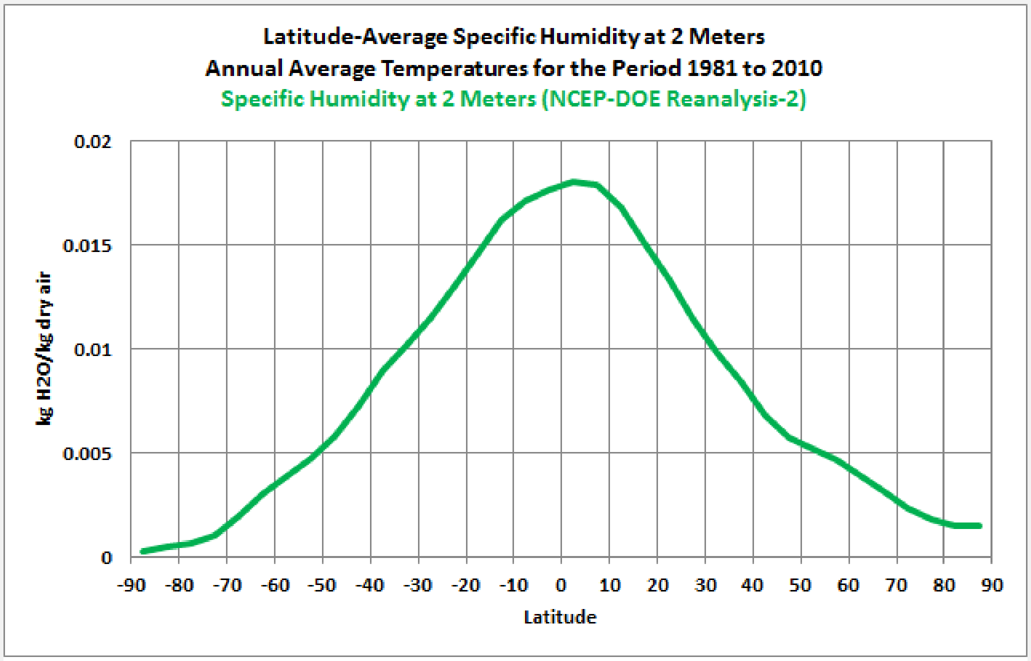


Figure 3.1-5

And that leaves one more metric to present, before we move on to the discussion of the processes that drive atmospheric circulation. That metric is specific humidity, which represents the mass of the moisture held by the atmosphere compared to the mass of the air. It is presented in terms of the ratio of water vapor to dry air—expressed in kilograms of water vapor per kilogram of dry air—at 2 meters above the surface. The specific humidity output shown in Figure 3.1-5 is also a product of the NCEP-DOE Reanalysis-2. (Again, that reanalysis is no longer available in easy-to-use form online. Sorry.)

Because the air is warmer in the tropics, it can hold more moisture than the air at the poles.

That confirms the opening statement that the air is warmer and moister in the tropics than at the poles, because sunlight is stronger in the tropics than at high latitudes.

In response to the differences in the amount of solar energy reaching the surface of the planet, atmospheric circulation is one of the means through which that energy is redistributed from the tropics toward the poles.

Or looking at in in a slightly different light, because more sunlight reaches Earth's surface in the tropics than at the poles, there is an energy imbalance. The atmosphere and oceans circulate heat from the tropics to the pole, and in doing so, they work to reduce that energy imbalance.

HADLEY CIRCULATION AND THE TRADE WINDS

Because the ocean and land surfaces are so warm in the tropics, the warm, moist air rises there. In response to that rising air, replacement air near the surface is drawn toward the equator in both hemispheres. Because the Earth is rotating, that inrushing, equator-ward wind is deflected toward the west due to the Coriolis effect. Those winds are known as the trade winds. The trade winds travel from the northeast to the southwest in the tropics of the northern hemisphere and from the southeast to the northwest in the tropical southern hemisphere. See Figure 3.1-6.

At higher altitudes, the warm, moist is carried poleward in both hemispheres, cooling and releasing moisture as rain along the way. The cooler, drier air falls back toward the surface at the subtropical latitudes of 35S-30S and 30N-35N, also known as the horse latitudes. And then some of it heads back toward the equator, warming and becoming more moist, to complete the "circuits". Those circuits in both hemispheres are known as Hadley cells. They're named for George Hadley, a British amateur meteorologist, who proposed the mechanism for why the trade winds blow from east to west.

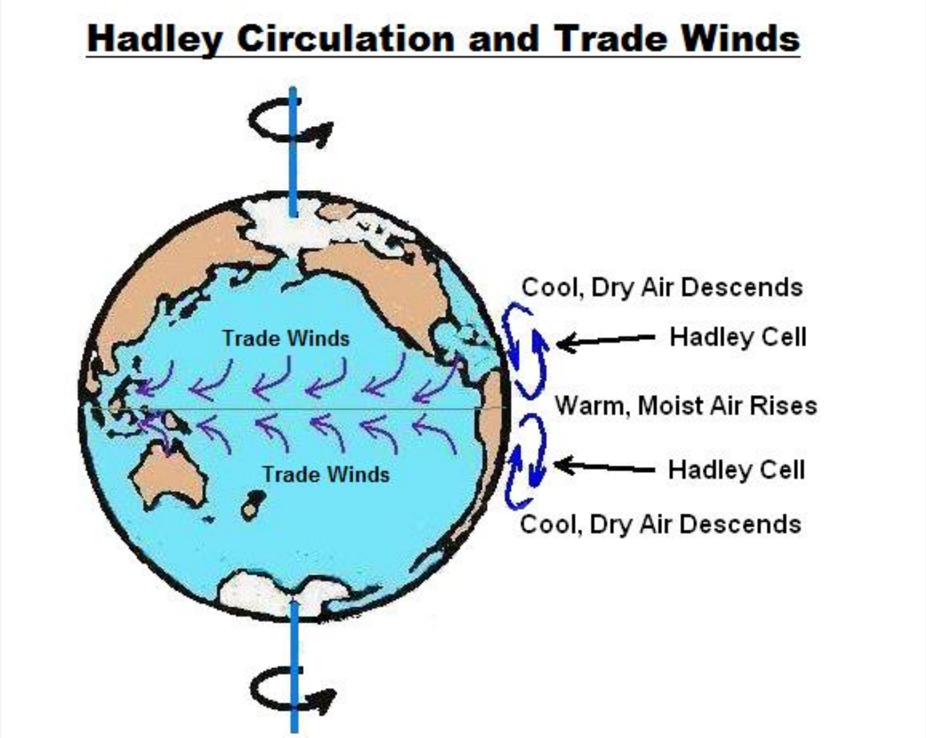


Figure 3.1-6

FERREL CELLS

Ferrel cells were named for William Ferrel, an American meteorologist who developed the theories behind atmospheric circulation at mid-latitudes. Ferrel cells stretch from the horse latitudes to about 45-60 degrees latitude in both hemispheres. See Figure 3.1-7.

Cool dry air descends in the horse latitudes, with some of it traveling north. As the surface winds travel north, they are deflected to the east by the Coriolis effect, creating the prevailing westerlies. The surface winds pick up moisture and eventually rise at about 45 to 60 degrees latitude in both hemispheres. At higher altitudes, the warmer, moister air cools and loses moisture as it travels south, until it descends once again in the horse latitudes, completing the Ferrel cell.

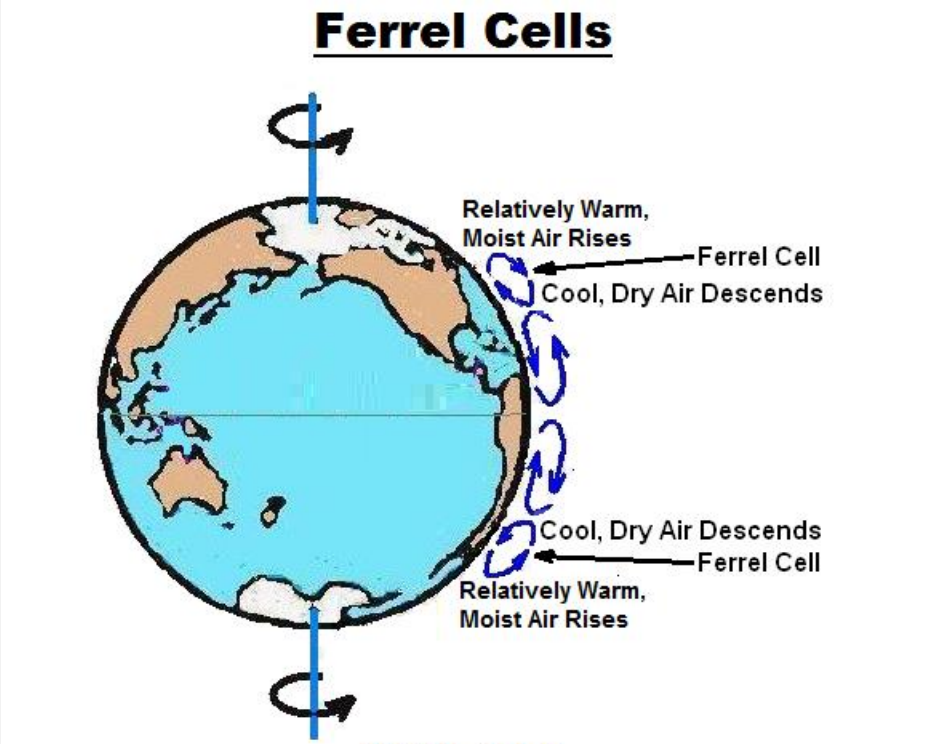


Figure 3.1-7

POLAR CELLS

As their name suggest, polar cells are found in the polar regions of the northern and southern hemispheres. See Figure 3.1-8. Cold, dry air descends at the poles. It then spreads out, traveling toward lower latitudes. The Coriolis effect deflects it toward the west, creating “surface polar easterlies”. That cold polar surface air travels to the southwest in the northern hemisphere and to the northwest in the southern hemisphere, and it eventually collides at about 45 to 60 degree latitude with the warmer, wetter air from the lower-latitude Ferrel cells. There it rises and heads toward the poles again to complete the polar cell.

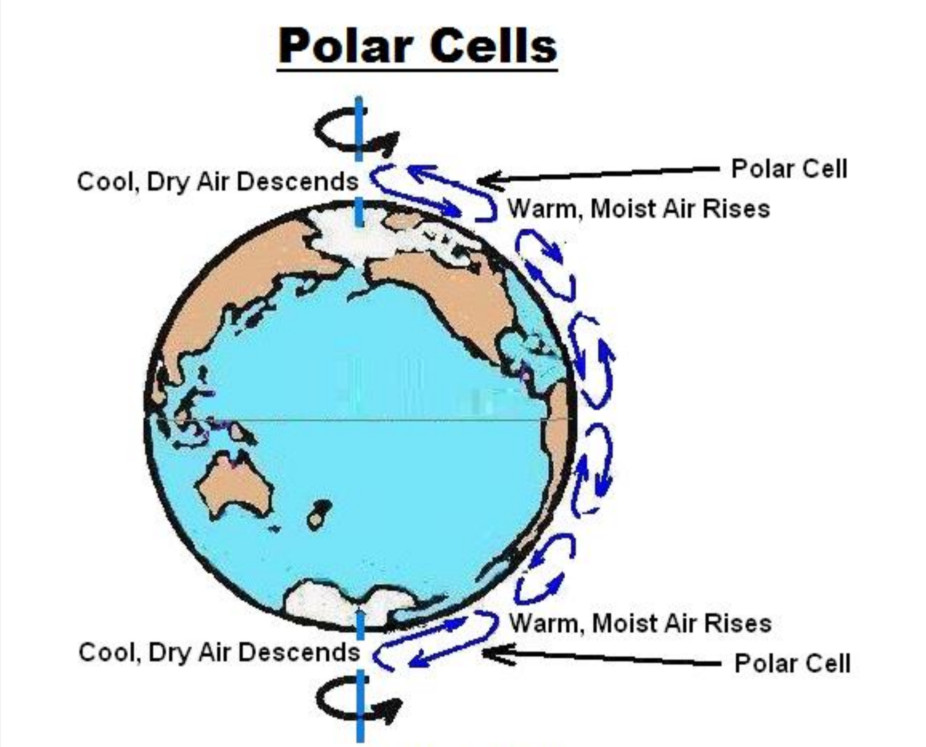


Figure 3.1-8

HIGH AND LOW PRESSURE BANDS

Wherever warm, moist air rises from the surface, an area of low pressure is created at the surface. Conversely, areas of high pressure are created at the surface where cool, dry air descends from altitude to the surface. See Figure 3.1-9. Surface winds blow from the area with high surface pressure to the region with the low surface pressure.

Low pressure regions are associated with the warm, moist air rising into the atmosphere where it cools and form clouds. As a result, precipitation occurs more frequently in and around the low pressure regions. Conversely, the air is much dryer along the bands where the surface pressures are high, which is why they are associated with desert regions.

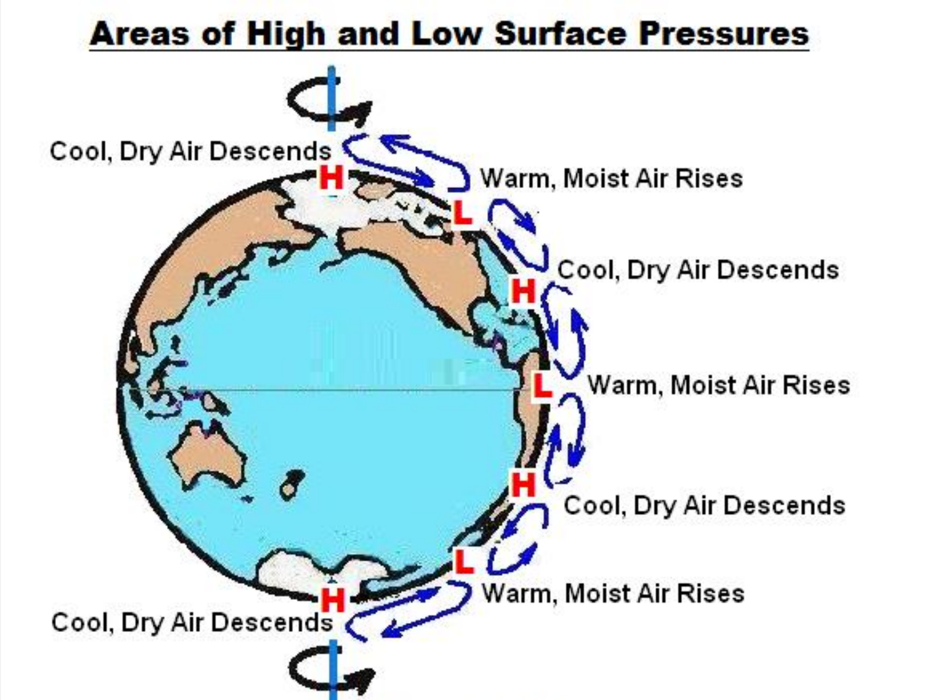


Figure 3.1-9

THE JET STREAMS

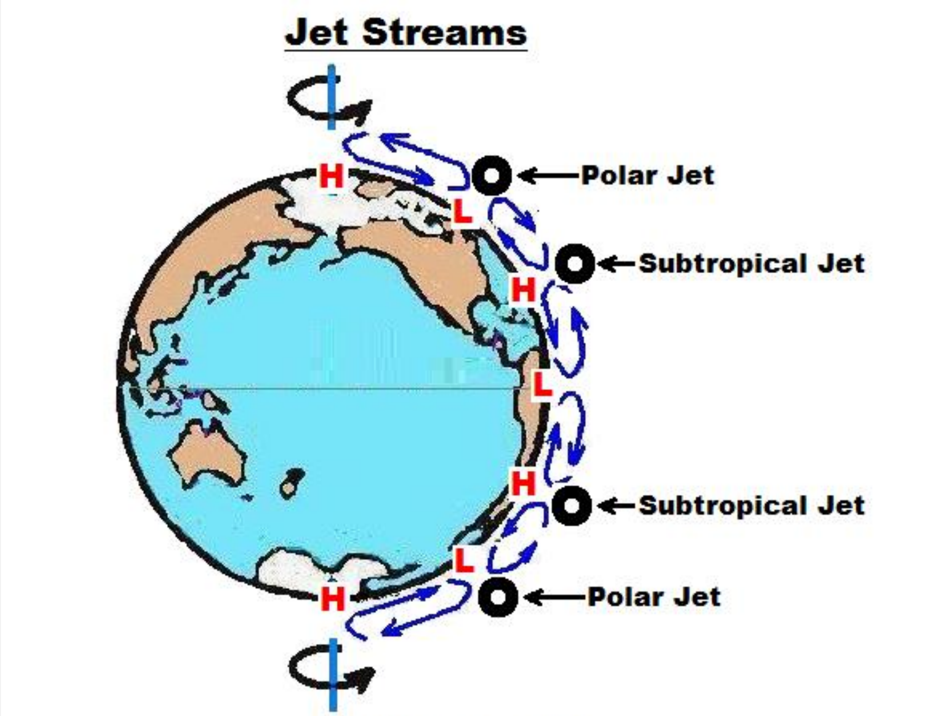


Figure 3.1-10

The relatively tight bands of high-speed winds that travel, in general, from west to east in the upper levels of the atmosphere are called jet streams. The “polar jets” occur where the polar and Ferrel cells meet, and the “subtropical jets” occur where the Ferrel and Hadley cells meet. See Figure 3.1-10. Winds are strongest at the boundaries where warm, wet air meets cool, dry air. In turn, in the upper atmosphere, those regions also have the strongest winds.

The locations of the jet streams at any given time depend of many variables, and they can and do meander closer to and farther from the poles and equator. That indicates the polar, Ferrel and Hadley cells are varying in size and shape. See Figure 3.1-11. Sometimes the jet streams blow from north to south and sometimes from south and north.

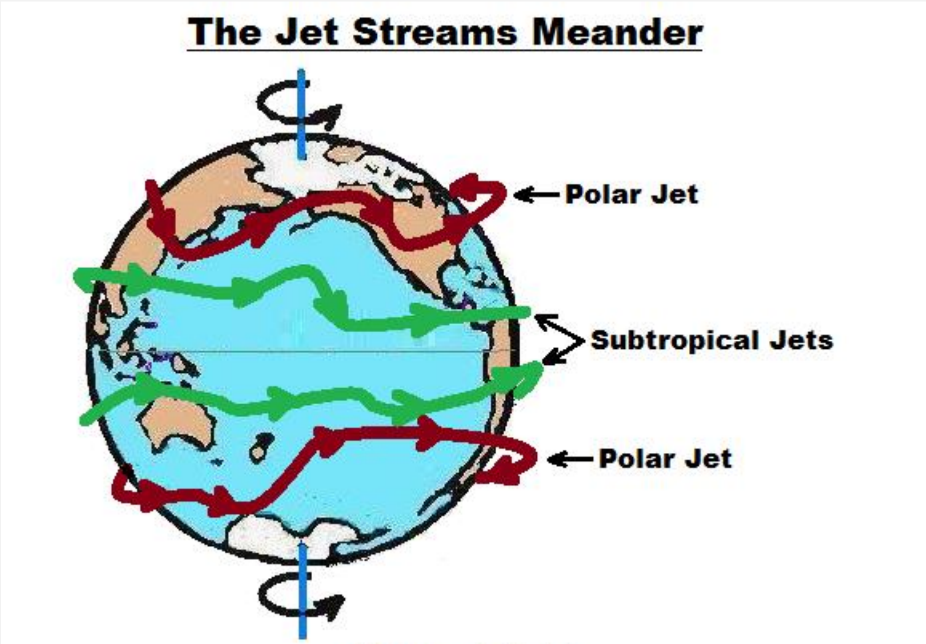


Figure 3.1-11

IMPACTS OF ATMOSPHERIC CIRCULATION ON GLOBAL PRECIPITATION

Earlier we noted how warm, moist air rises near the equator and at the latitudes where the polar and Ferrel cells meet. As that warm, moist air rises into the atmosphere, where it is gradually colder, the moisture in the air condenses (releasing heat to the atmosphere, latent heating), forms clouds and then falls as rain or snow. We also noted that at the latitudes where the Hadley and Ferrel cells meet, the air is cooler and drier. At those latitudes, we would expect much less precipitation. We can confirm the distribution of precipitation by looking at the annual average precipitation data on a latitude average basis. For the graph in Figure 3.1-12, we’ll use the period of 1981 to 2010. It doesn’t quite fit the expected locations of the horse latitudes and the polar fronts. And we'll discuss why in a few moments. For the dataset, we're using NOAA's Global Precipitation Climatology Project (GCPC) Version 2.2, which is one of the precipitation datasets available through the KNMI Climate Explorer. The data are based on satellite estimates globally and on rain gauges on land. As shown, the highest annual precipitation happens near the equator. The precipitation then drops off rapidly in both hemispheres, reaching the bottom of a trough near 20 to 25 latitude north and south, before rising again in mid-latitudes. Annual precipitation then drops off to its minimums near both poles.

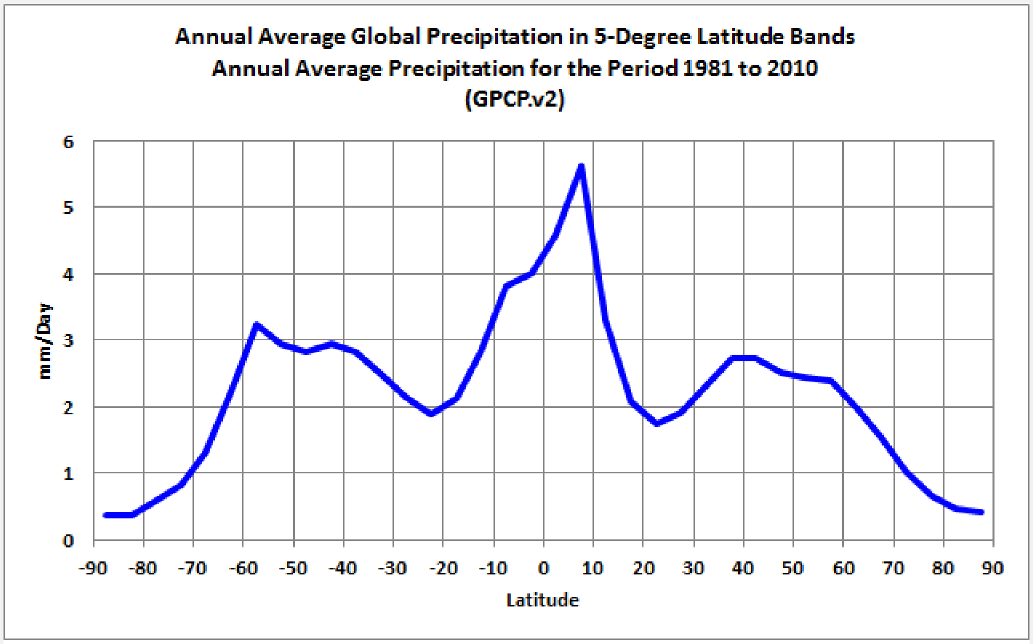


Figure 3.1-12

You'll note that the annual precipitation in the hemispheres is not symmetrical; that is, the precipitation rates in the hemispheres are not mirror images of one another. Near the equator, the Inter-tropical Convergence Zone is offset toward the northern hemisphere by the locations and altitudes of land masses near the equator and by ocean temperature patterns along the equator, especially in the Pacific.

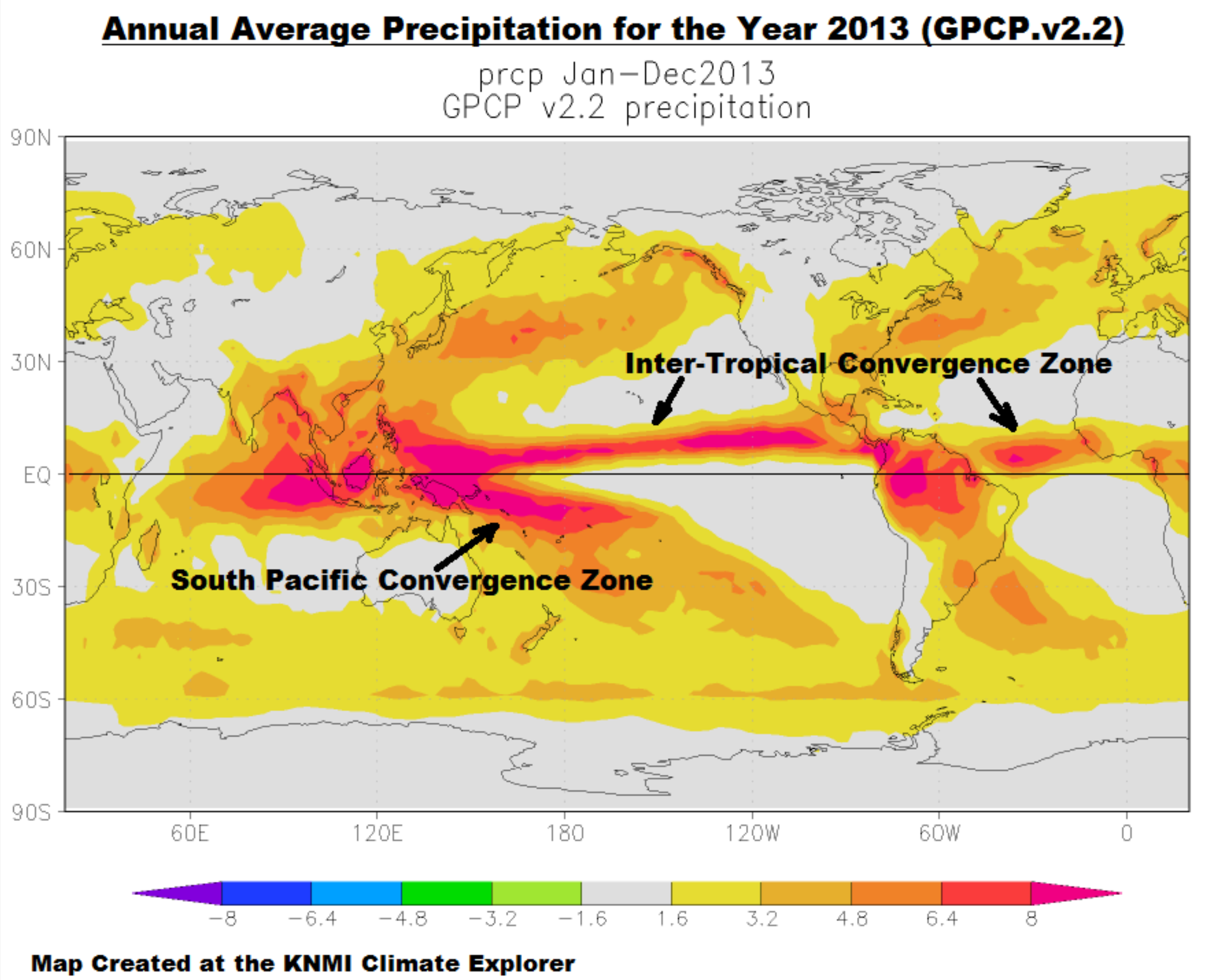


Figure 3.1-13

To confirm part of that, Figure 3.1-13 shows global annual average precipitation for 2013. That was an ENSO-neutral year, meaning it wasn't impacted by an El Niño or La Niña in the tropical Pacific, so it would better represent an "average" year than had we looked at a year when there was an El Niño or La Niña. I've pointed to the Inter-Tropical Convergence Zones (ITCZ) in the Pacific and Atlantic Oceans. I've also noted the location of the South Pacific Convergence Zone (SPCZ) that extends from the western equatorial Pacific to the southeast, in the general direction of the tip of South America. The South Pacific Convergence Zone will be mentioned a few times later in the book. You'll notice how more precipitation falls over the oceans than land. In the North Pacific and North Atlantic, the precipitation is also greater in the western portions (where the water is warmer) than in the eastern portions (where the water is cooler). So in addition to atmospheric circulation, ocean circulation also impacts global precipitation patterns.

Figure 3.1-14 is a map of annual average sea surface temperatures (not anomalies), also for 2013, as a reference. Note how the surface temperature of the eastern equatorial Pacific is cooler than in the western equatorial Pacific, and how the warmer water resides north of the equator in the eastern tropical Pacific. The same thing happens in the equatorial Atlantic. More convection occurs where the water is warmer, so the Inter-tropical Convergence Zone, on average for a year, is north of the equator. The area of cooler waters in the eastern equatorial Pacific is called the "Cold Tongue Region".

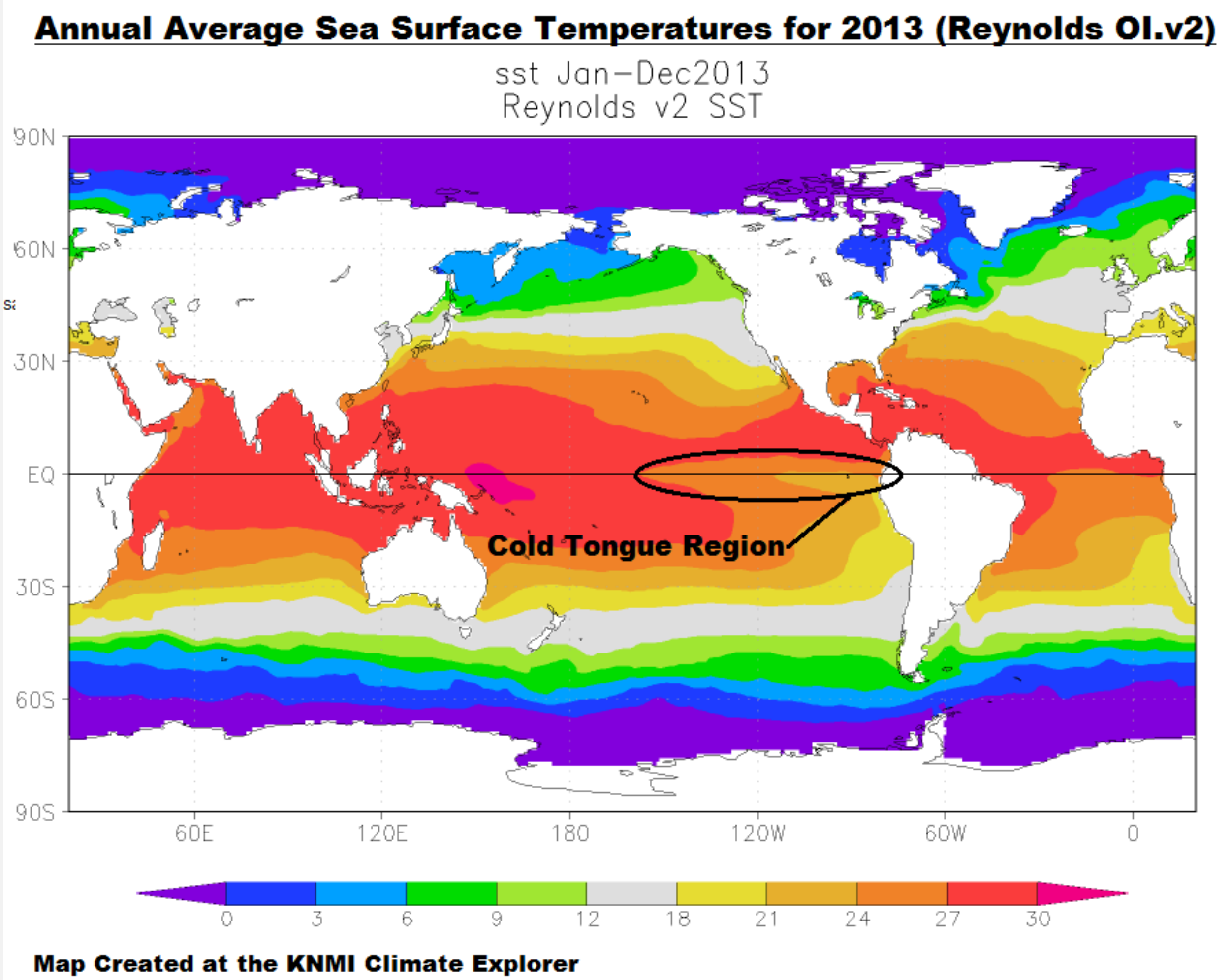


Figure 3.1-14

The location of the Inter-Tropical Convergence Zone varies over the course of a year. As the seasons vary, the warmest waters cycle back and forth across the equator, following the sun. The Inter-Tropical Convergence Zone accompanies the warmest water.

We'll discuss the reasons for the Cold Tongue Region in the next chapter, which is about ocean circulation.

ADDITIONAL INTRODUCTIONS

There are a number of easy-to-understand introductions to atmospheric circulation. They include the following webpages:

- Convection from the University of Illinois at Urbana-Champaign
- Global Circulation Patterns from the UK Met Office
- Global Circulations from NOAA’s National Weather Service
- General Circulation of the Atmosphere from the University of Wisconsin
- Air Circulation from the University of Oklahoma

3.2 – Introduction to Ocean Circulation

Ocean circulation is the other means through which the Earth distributes heat from the tropics to the poles. NASA has an excellent educational website about ocean circulation called OceanMotion. The links throughout this chapter are primarily to the OceanMotion webpages. The following is a very basic introduction. Refer to the OceanMotion website for more detail.

TRADE WINDS DRIVE EQUATORIAL OCEAN CURRENTS

In the previous chapter, we noted how and why surface temperatures are warmest in the tropics and that a tremendous amount of convection (rising air) occurs there. (See the discussion of the Hadley Cell and the Trade Winds.) Along the surface, subtropical air in both hemispheres rushes toward the equator to replace that rising air. The rotation of the Earth deflects that inrushing air toward the west. As a result, those surface winds, called the trade winds, travel along the surface of the tropical oceans from the northeast to southwest in the northern hemisphere and from the southeast to the northwest in the southern hemisphere, meeting near the equator at the Inter-Tropical Convergence Zone (ITCZ).

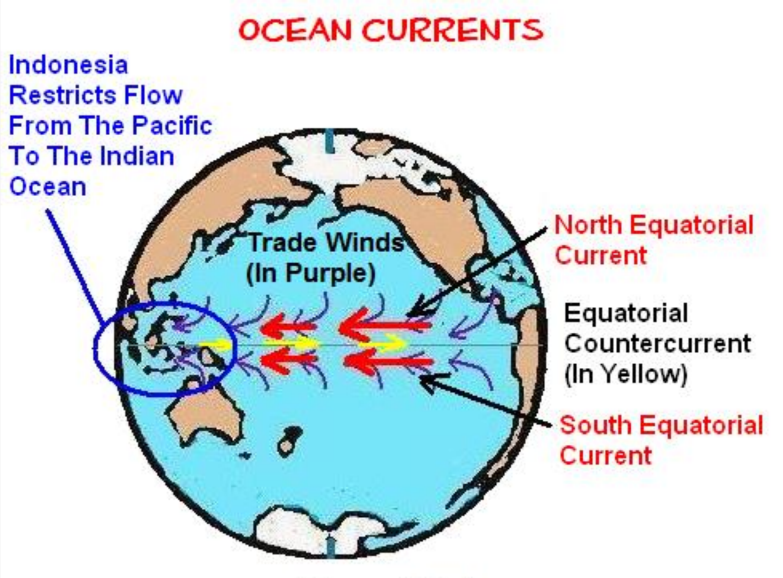


Figure 3.2-1

The trade winds push the tropical surface waters of the oceans from east to west, creating the equatorial currents in both hemispheres. See Figure 3.2-1. Equatorial currents exist in the three primary ocean basins: Atlantic, Indian and Pacific. There are also much smaller currents that travel from west to east along the equator, between the north and south equatorial currents, and those small opposing currents are called Equatorial Countercurrents.

LAND MASSES LIMIT THE WESTWARD FLOW OF TROPICAL WATERS

The equatorial currents of the three ocean basins run into land. In the Atlantic, they encounter South America. In the Indian Ocean, as the waters travel west, they run into the east coast of Africa. For the Pacific, the landmasses of Australia and Indonesia restrict (but do not totally block) the westward movement of waters of the north and south equatorial currents. With nowhere else to go, the waters head toward the poles. The currents traveling poleward along the western coasts of the ocean basins (east coasts of the continents) are called western boundary currents. In the western North Atlantic, that western boundary current is known as the Gulf Stream. The Kuroshio Current is the western boundary current in the North Pacific, traveling northward along the east coast of Asia.

In the tropics, at the eastern coastlines of the ocean basins (west coasts of the continents), the waters are being driven westward by the trade winds away from the coasts. That water has to be replenished, so waters from higher latitudes travel toward the equator in both hemispheres along those coastal boundaries. Those are called the eastern boundary currents (which are also discussed at OceanMotion webpage here, toward the end).

The westerlies (west to east winds) push the surface waters from the western boundary currents to the eastern boundary currents at mid-latitudes, completing the circuits.

GYRES

Full-sized version of Figure 3.2-2 is here. It is a map of ocean currents available from Wikimedia Commons here. The map is based on a map published in the 1943 Army Service Forces Manual M-101: Atlas of World Maps for the Study of Geography in the Army Specialized Training Division. A copy of the original is here.

Gyres refer to the long-term patterns of rotational flow of ocean surface waters. There are subtropical gyres, which were described above. The subtropical gyre in the North Atlantic includes a North Equatorial Current (driven east to west by the trade winds), the Gulf Stream (the western boundary current), the North Atlantic Current (driven from west to east by the westerlies), and the Canary Current (the eastern boundary current). And the subtropical gyre in the North Pacific includes a North Equatorial Current (driven east to west by the trade winds), the Kuroshio Current (the western boundary current), the North Pacific Current (driven from west to east by the westerlies), and the California Current (the eastern boundary current).

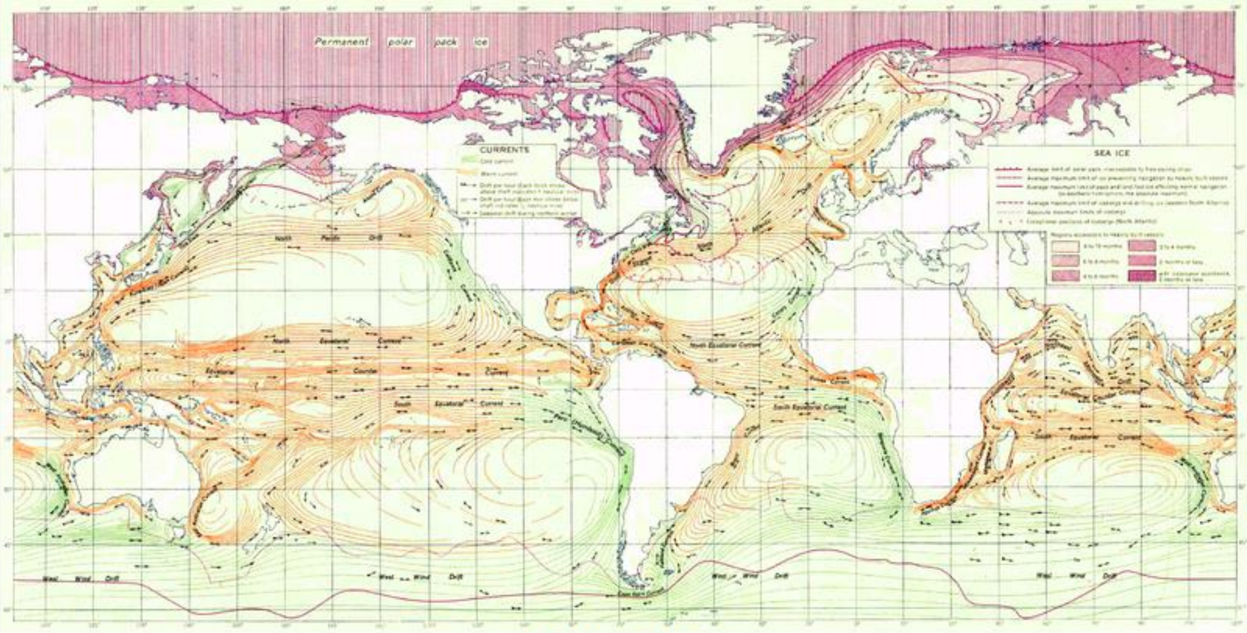


Figure 3.2-2

In the Northern Hemisphere, there are also sub-polar gyres. The southern boundary currents of the sub-polar gyres are the northern boundary currents of the subtropical gyres, but the eastern boundary currents of sub-polar gyres head toward the poles; thus creating rotation that is the opposite of the subtropical gyres. That is, while the subtropical gyres in the northern hemisphere rotate clockwise when viewed from above, the sub-polar gyres rotate counterclockwise. The sub-polar gyre in the North Pacific is easy to make out in the current map (Figure 3.2-2). In the North Atlantic, the sub-polar gyre resides south of Greenland and east of Labrador, Canada.

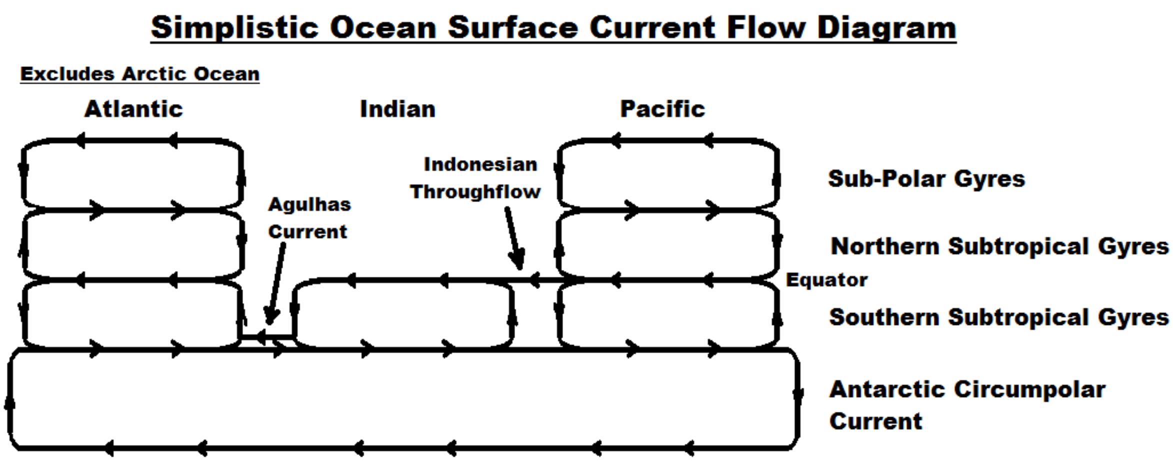


Figure 3.2-3

In the Southern Hemisphere, the east to west flowing Antarctic Circumpolar Current (ACC) serves as the southern boundaries for the subtropical gyres in the South Atlantic, the South Indian and the South Pacific. The Antarctic Circumpolar Current circles the continent of Antarctica. Its flow is only restricted at the Drake Passage, which is the 800 km (500 mile) wide body of water between Antarctica's South Shetland Islands and Cape Horn at the southern tip of South America. The Antarctic Circumpolar Current is the only ocean current to circle the globe. As such it serves as the only place where the surface waters from all ocean basins are "mixed". See Figure 3.2-3, which is a very simple flow chart of ocean surface currents (excluding the Arctic Ocean). The Agulhas Current is the western boundary current in the South Indian Ocean, but it also extends around the Cape of Good Hope carrying waters from the South Indian to the South Atlantic. And the Indonesian Throughflow is the current that carries water from the tropical Pacific Ocean into the tropical Indian Ocean.

DISTRIBUTION OF HEAT

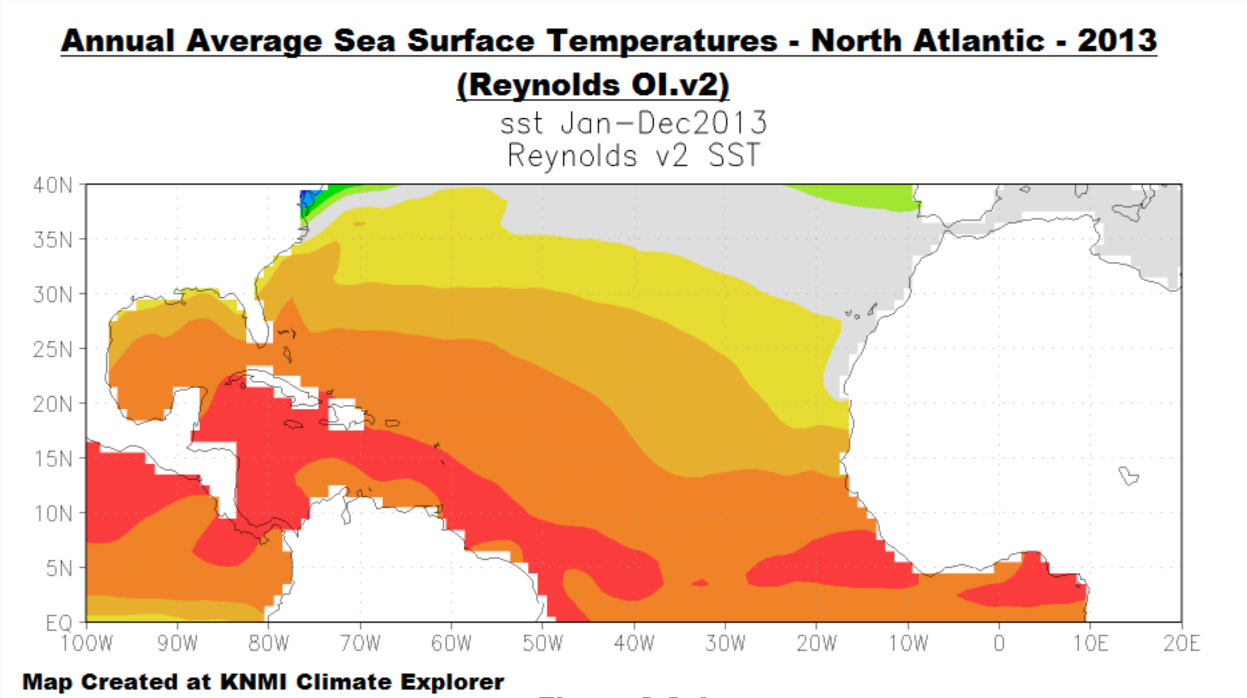


Figure 3.2-4

We confirmed in the previous chapter that sunlight is brightest in the tropics. The oceans cover about 76% of the surfaces of the tropics. Those sunlight-warmed waters are carried west by the equatorial currents in both hemispheres. The western boundary currents then carry that sunlight-warmed water poleward, where it's cooler, with the oceans releasing heat to the atmosphere along the way. The cooler waters are then returned to the tropics by the eastern boundary currents. See Figure 3.2-4 for an example of the distribution (spatial pattern) of sea surface temperatures for an ocean basin. It presents the average sea surface temperatures (absolute, not anomalies) for the tropical and subtropical North Atlantic for 2013.

We can see that the average sea surface temperatures in 2013 were cooler along the coast of Africa than they were in the Caribbean, the Gulf of Mexico and along the southern eastern seaboard of the United States.

So, in addition to atmospheric circulation, ocean circulation also contributes to the transport of heat from the tropics to the poles.

THE OCEANS ALSO CIRCULATE WATERS TO AND FROM THE DEPTHS

The oceans also have depth, and ocean waters circulate from the surface to depth and from the depths to the surface. Upwelling and downwelling are the terms used to describe the vertical movement of waters. Upwelling and downwelling occur along coastlines and out in the middle of the oceans.

Along the coasts, the vertical movement of ocean waters is caused by the rotation of the Earth (the Coriolis effect), by persistent winds, by the shape of the coastlines and by the depths of the local ocean bottoms. If the surface winds are such that surface waters are driven toward the coast, then warmer surface waters will be driven, downwelled, to the ocean depths. Conversely, if the direction of the wind is such that the surface waters move away from the coast, then cool subsurface waters will be upwelled near the coast as “replacement” for waters that are leaving. The OceanMotion webpage for upwelling and downwelling uses the term “mass continuity” to describe, in part, that “replacement”. There they note:

> *Upwelling and downwelling illustrate mass continuity in the ocean; that is, water is a continuous fluid so that a change in distribution of water in one area is accompanied by a compensating change in water distribution in another area.*

The description also suggests that if upwelling is occurring somewhere in the ocean, then downwelling has to be occurring somewhere else.

Coastal upwelling occurs primarily along the western coasts of the continents (eastern coasts of the oceans): the California and western North African coasts in the Northern Hemisphere and in the Southern Hemisphere, Chile and the western South African coasts.

Upwelling also occurs along the equator. The trade winds drive the surface currents from east to west, but they also cause the surface waters near the equator to be driven poleward in both hemispheres. (Refer to the OceanMotion discussion of Ekman transport.) To replace that poleward-moving surface water, cooler subsurface waters are upwelled to the surface along the equator. In fact, as an example, we often hear the term La Niña being used to describe “an unusual” cooling of the surface of the eastern and central equatorial Pacific. There’s really nothing unusual about it. The La Niña is simply a natural response to the occasion strengthening of the trade winds. With the stronger trade winds, there is more upwelling of cool subsurface waters along the equatorial Pacific. Simple. We'll discuss La Niña and El Niño events in an upcoming chapter.

THERMOHALINE CIRCULATION

There is also a density-driven form of ocean downwelling. Vertical (surface to depths) transport of waters are also caused by the temperature (thermo-) and salinity (-haline) of the ocean at high latitudes. Thus, it's called thermohaline circulation. The temperatures of the abyssal oceans are approximately 2 to 3 deg C (35 to 37 deg F). The freezing temperature of sea surface waters, on the other hand, is about -2.0 deg C (28 deg F). Looking at the temperatures of the surface and abyssal oceans, the surface waters can be more dense than the waters deep in the oceans. Being more dense, the surface waters sink. But there is another, even more important, factor, and it's the salinity of the ocean water.

The National Snow and Ice Data Center (NSIDC) webpage Salinity and Brine provides an easy-to-understand description of ocean salinity (the saltiness of the ocean water) and how that salinity changes when sea ice freezes and melts. There they write in the closing paragraph:

> *Salt plays an important role in ocean circulation. In cold, polar regions, changes in salinity affect ocean density more than changes in temperature. When salt is ejected into the ocean as sea ice forms, the water's salinity increases. Because salt water is heavier, the density of the water increases and the water sinks. The exchange of salt between sea ice and the ocean influences ocean circulation across hundreds of kilometers.*

THERMOHALINE CIRCULATION AND MERIDIONAL OVERTURNING CIRCULATION

Thermohaline circulation and the term Meridional Overturning Circulation are often used interchangeably. For the North Atlantic, you'll often see the term Atlantic Meridional Overturning Circulation (AMOC). Thermohaline circulation, as noted above, is the ocean circulation caused by the temperature and salinity (both of which impact the density) of the ocean waters. Meridional overturning circulation is a term that describes the results of thermohaline circulation. "Meridional" refers to circulation that occurs in the North-South or South-North directions, and overturning indicates the waters sink (downwell) and resurface (upwell). Typically, the term Meridional Overturning Circulation refers to the circuit resulting from the downwelling of waters at high latitudes and the upwelling at low latitudes. The NSIDC Environment: climate webpage has a nice description of this process under the heading of Atmosphere and Ocean Circulation:

> *The atmosphere and ocean act as "heat engines," always trying to restore a temperature balance by transporting heat toward the poles. Our weather is a manifestation of this phenomenon. Low-pressure systems, such as storms, which can be especially strong in winter, are one of nature's best ways of transporting heat poleward by atmospheric circulation. The oceans, by contrast, tend to transport heat in a slower and less violent fashion. Changes in the amount of sea ice alter how cold the poles are, which could affect atmospheric and ocean circulation.*
>
> *Ocean currents transport heat from the equator to the poles through a heat- and saline-driven process called thermohaline circulation.* ***Warm water moves from the equator northward along the ocean surface and eventually cools. As it cools, it becomes dense and heavy and sinks. This cold water then moves south along the lower part of the ocean and rises near the equator to complete the cycle****. Like the atmospheric heat transport discussed earlier, this is a natural process that contributes to a proper temperature balance across the earth. It also explains why Europe is relatively warm, because as northward flowing surface water in the Atlantic Ocean cools, heat is released to the atmosphere.*

The OceanMotion webpage Ocean Conveyor Belt Impact includes a simple video presentation of Thermohaline Circulation (Meridional Overturning Circulation). The Windows media version (.wmv) is here and Quicktime version (.mov) is here. The cold and salty water sinks (downwells) at the high latitudes of the North Atlantic and then rises to the surface again (upwells) near the equator. It is believed that a "complete circuit" associated with this type of circulation (downwelling at high latitudes and then upwelling near the equator) takes a few decades. In fact, there are papers that describe meridional overturning circulation taking place at different depths of the oceans, with the deeper circulations, as you could imagine, taking much longer to complete a "circuit" than the shallow meridional overturning circulation.

THERMOHALINE CIRCULATION AND THE GLOBAL OCEANIC CONVEYOR BELT

Many people think of the great oceanic conveyor belt when they hear the term thermohaline circulation. The OceanMotion webpage Oceanic Conveyor Belt Background begins:

> *The* ***global oceanic conveyer belt…****is a unifying concept that connects the ocean's surface and thermohaline (deep mass) circulation regimes, transporting heat and salt on a planetary scale.*

Figure 3.2.-5 includes two of the many presentations of ocean circulation associated with the global oceanic conveyor belt. The simpler presentation on the left is from the NOAA National Weather Service educational webpage Ocean Circulations, and the more complex presentation of the conveyor belt on the right is from the World Meteorological Organization (WMO) bulletin Observing the polar oceans during the International Polar Year and beyond.

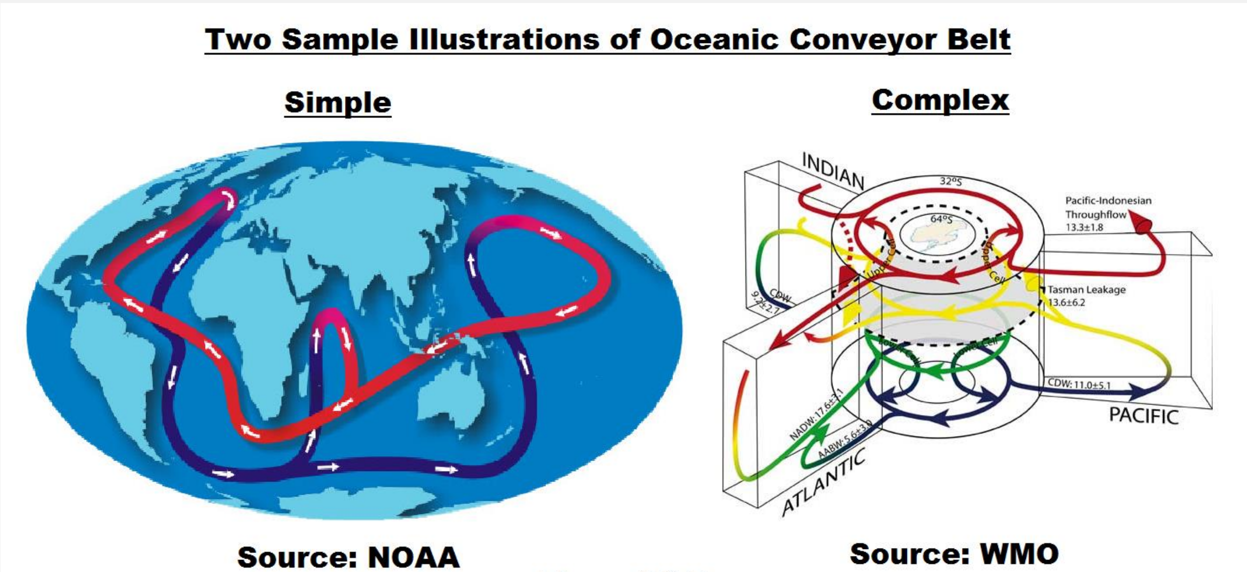


Figure 3.2-5

The concept of the global oceanic conveyor belt is based on sound physics. The ocean will circulate waters from the region where the density is greater (the high latitudes of the North Atlantic) to the regions where it is less dense (the Indian and Pacific Oceans). The paths taken by the waters are theoretical and the hypothetical time taken to complete a "cycle" is thought to take upwards of 1500 years. Those are, obviously, estimates that cannot be verified with measurements.

OCEAN CIRCULATION ALARMISM DEFIES NATURE

About a decade ago, there was alarmism about the "possibility" of the Gulf Stream stopping. See the February 2004 *Nature News* article Gulf Stream probed for early warnings of system failure. They write (my boldface):

> *Climatologists worry that global warming could disrupt these currents, which make Western Europe's climate far warmer than other parts of the world at the same latitude.* ***Without the Gulf Stream, for example, the south of England would be as cold as Iceland.***
>
> *Researchers think the currents are caused by a combination of wind, differences in water density, and the special geometry of Atlantic Ocean basins and the*

> *surrounding continents.* ***They think the system may have broken down before, driving large, abrupt changes in climate****.*

As you'll recall, that was the basis for the 2004 movie *The Day After Tomorrow*.

That sort of climate porn published in the scientific periodical *Nature* prompted a response from esteemed oceanography Carl Wunsch, a professor at Massachusetts Institute of Technology [emeritus] and visiting professor of oceanography at Harvard University. His letter to Nature is titled Gulf Stream safe if wind blows and world turns. It includes (my boldface):

> *European readers should be reassured that the Gulf Stream's existence is a consequence of the large-scale wind system over the North Atlantic Ocean, and of the nature of fluid motion on a rotating planet.* ***The only way to produce an ocean circulation without a Gulf Stream is either to turn off the wind system, or to stop the Earth's rotation, or both****.*

Let's run through that in more detail. As you'll recall, the trade winds drive the equatorial current in the North Atlantic. The equatorial current, in turn, feeds the Gulf Stream. In order for the Gulf Stream to stop, the equatorial current in the North Atlantic would have to stop, which means the trade winds would have to have stopped blowing. And the trade winds aren't about to stop blowing. The trade winds blow from east to west because of the temperature difference between the equator and the mid-latitudes and because the rotation of the Earth deflects the equatorward-blowing surface winds toward the west. So as Carl Wunsch said, "The only way to produce an ocean circulation without a Gulf Stream is either to turn off the wind system, or to stop the Earth's rotation, or both."

And Carl Wunsch's letter to Nature closes with:

> *The occurrence of a climate state without the Gulf Stream any time soon — within tens of millions of years — has a probability of little more than zero.*

Like the movie *The Day After Tomorrow,* climate science is once again shown to be nothing more than science fiction…fiction that defies the laws of nature.

And now the punchline: One of the papers that predicted the halt of the Gulf Stream relied on 2 flow readings, but they were from different seasons in different years. The researchers didn't understand that there was a seasonal component to the strength of the Gulf Stream current, where it's stronger during some seasons than others. They mistakenly viewed the slowing from one season to another as a precursor for calamity. It would be like taking a temperature measurement during the summer of one year, then coming back two and a half years later and discovering the temperature was colder in winter…and predicting an ice age is coming. Thus is climate science.

The already-debunked thought that the Gulf Stream could stop has been recently raised again. See the September 8, 2015 *Sydney Morning Herald* article New climate-change studies deepen concerns about a northern chill.

ADDITIONAL INFORMATION ABOUT OCEAN CIRCULATION

There are a number of great tutorials about ocean circulation on the internet, all of which provide the same basic information, but sometimes the differences in how concepts are worded can help our understanding. Please see for example:

- NASA OceanMotion website beginning at Patterns of Circulation Background
- NOAA Ocean Service Education webpage Currents

3.3 – Ocean Mode: Atlantic Multidecadal Oscillation

Initial Note: This chapter was initially prepared in 2014. I've updated some of the graphs where necessary.

# # #

The Atlantic Multidecadal Oscillation or AMO is a mode of natural variability that makes its presence known in the sea surface temperatures of the North Atlantic. It does extend into the tropical South Atlantic but at a much reduced rate. The Atlantic Multidecadal Oscillation is also evident in the subsurface temperature data of the North Atlantic and, in turn, the ocean heat content data to the depths of 2000 meters (6600 feet).

The NOAA Physical Oceanography Division (PhOD) has the very informative webpage Frequently Asked Questions About the *Atlantic Multidecadal Oscillation (AMO)*. There, NOAA provides the following definition of the Atlantic Multidecadal Oscillation (AMO) (My boldface):

> *The AMO is an ongoing series of* ***long-duration changes in the sea surface temperature*** *of the North Atlantic Ocean, with cool and warm phases that may last for 20-40 years at a time and a difference of about 1°F between extremes.* ***These changes are natural*** *and have been occurring for at least the last 1,000 years.*

In other words, a complete cycle of the Atlantic Multidecadal Oscillation can last for 40 to 80 years, and the peak variations can be about +/- 0.275 Deg C (0.5 deg F) in the sea surface temperatures of the entire North Atlantic Ocean. There is also evidence, apparently in paleoclimatological data, that the Atlantic Multidecadal Oscillation has existed for a long time. That is, it is not a mode of variability that has appeared in recent decades as a result of hypothetical man-made global warming.

Outside of the North Atlantic, the Atlantic Multidecadal Oscillation has strong impacts on land surface air temperatures and rainfall (drought) patterns in the Northern Hemisphere. Studies have also determined that the Atlantic Multidecadal Oscillation impacts the frequency and strength of hurricanes in the North Atlantic.

NOAA confirms that the Atlantic Multidecadal Oscillation is a naturally occurring phenomenon in their answer to the FAQ Is the AMO a natural phenomenon, or is it related to global warming?:

> *Instruments have observed AMO cycles only for the last 150 years, not long enough to conclusively answer this question. However, studies of paleoclimate*

proxies, such as tree rings and ice cores, have shown that oscillations similar to those observed instrumentally have been occurring for at least the last millennium. This is clearly longer than modern man has been affecting climate, so the AMO is probably a natural climate oscillation. In the 20th century, the climate swings of the AMO have alternately camouflaged and exaggerated the effects of global warming, and made attribution of global warming more difficult to ascertain.

That's curious. How often have you heard that a naturally occurring process—one that causes variations in the sea surface temperatures of the North Atlantic—has contributed to the warming we've experienced since the mid-1970s?

NORTH ATLANTIC SEA SURFACE TEMPERATURE ANOMALIES

Background discussion: Figure 3.3-1 presents the monthly sea surface temperature anomalies of the North Atlantic using the coordinates of 0-70N, 80W-0. Those are the coordinates used by the NOAA Earth System Research Laboratory (ESRL) for their Atlantic Multidecadal Oscillation Index. The dataset is the UKMO HADSST3. (HADSST3 data are available through the KNMI Climate Explorer.) The data in Figure 3.3-1 cover the period of January 1870 to present. Also included is the warming rate (linear trend) as determined by the EXCEL spreadsheet software…a not-very-alarming +0.04 deg C/decade.

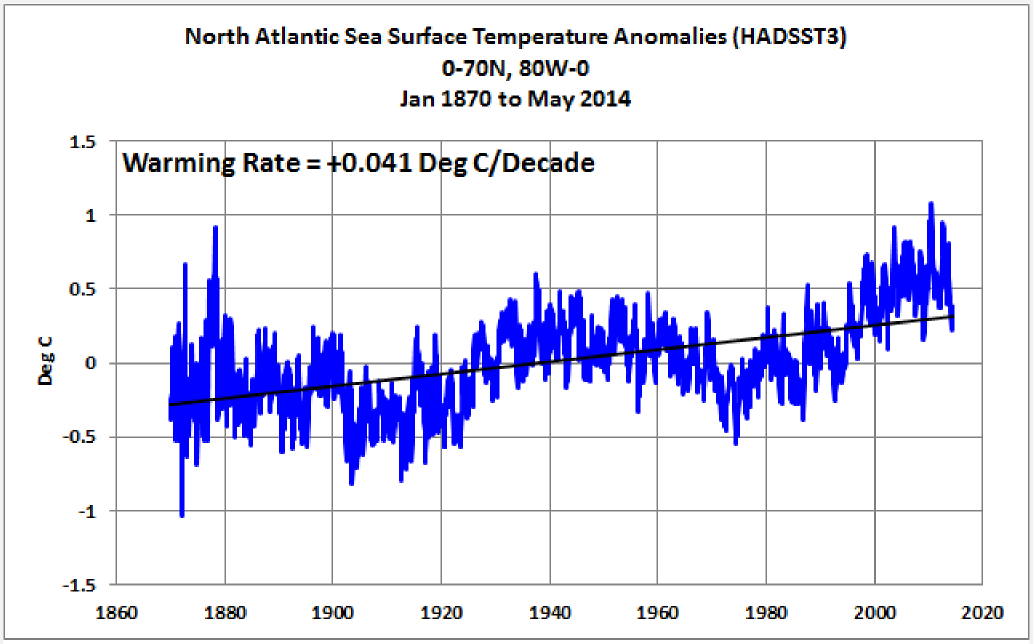


Figure 3.3-1

It's easy to see that the sea surface temperatures in the North Atlantic vary on multidecadal timeframes. For some multidecadal periods, the North Atlantic sea surface temperature anomalies are well above the trend line, and during others, they are well below it. The correct way to view it, though, is that during some periods, the sea surface temperatures of the North Atlantic warm at a much faster rate than the long-term trend, and during other multidecadal periods, the temperatures flatten and can sometimes cool. We can also see that, during the recent warming period, the North Atlantic sea surface temperature anomalies warmed much faster than the long-term trend. And that's important, because the Atlantic Multidecadal Oscillation explains some of the global warming we've experienced since the mid-1970s. We'll confirm that with data later in this chapter.

DETRENDING AND SMOOTHING THE NORTH ATLANTIC SEA SURFACE TEMPERATURE DATA

The multidecadal variations are very obvious in the North Atlantic data, but to help highlight those variations, climate scientists will often "detrend" the sea surface temperature data of the North Atlantic. There's nothing magical about detrending. To detrend the data, the monthly values of the trend line are subtracted from the data. NOAA uses detrended North Atlantic sea surface temperature data for their Atlantic Multidecadal Oscillation Index.

NOTES: (1) NOAA uses the Kaplan sea surface temperature dataset for their Atlantic Multidecadal Oscillation Index. The Kaplan dataset ended in the early 2000s, and afterwards NOAA has been splicing to it their Reynolds OI.v2 data for updates. As a result, I have not presented any Kaplan sea surface temperature-based data in this discussion of the Atlantic Multidecadal Oscillation. (2) Detrended indices are constantly changing. Each month, as new data are added, the new data alters the trend, but it is a very slight change. This slightly different trend, in turn, impacts the monthly values of the detrended data over the entire term of the data, when the new trend values are subtracted from the data. This is why you'll see very slight changes in NOAA's AMO index from month to month [End notes.]

Figure 3.3-2 presents the detrended HADSST3-based sea surface temperature anomalies of the North Atlantic, using the same coordinates (0-70N, 80W-0) used by NOAA for their Atlantic Multidecadal Oscillation Index. As noted above, the multidecadal variations are easier to see with the data detrended. To make the multidecadal variations even easier to visualize, NOAA also smooths their Atlantic Multidecadal Oscillation Index data with a 121-month running-average filter. See Figure 3.3-3.

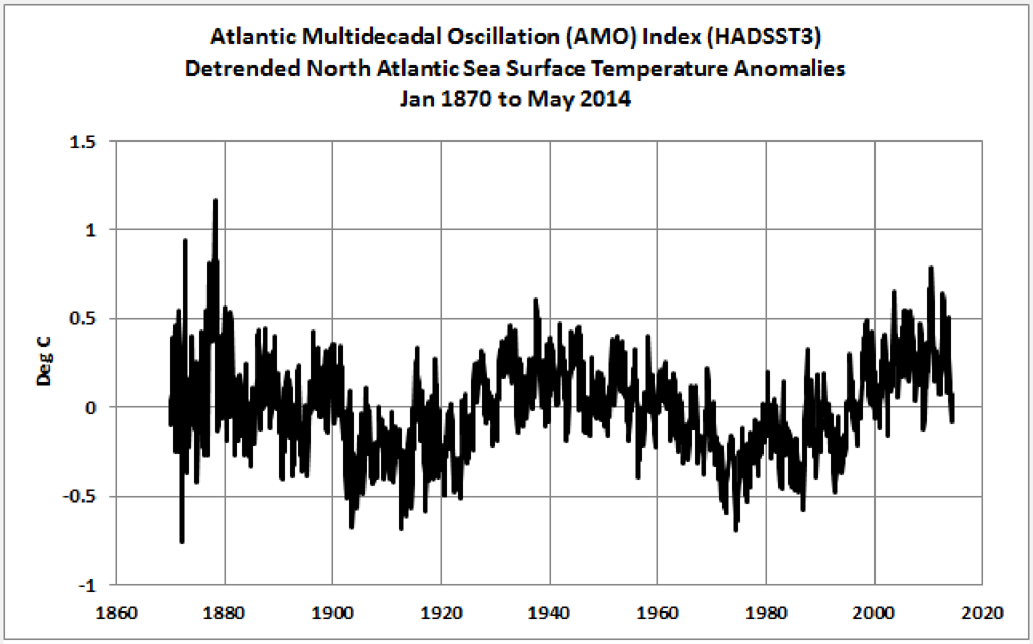


Figure 3.3-2

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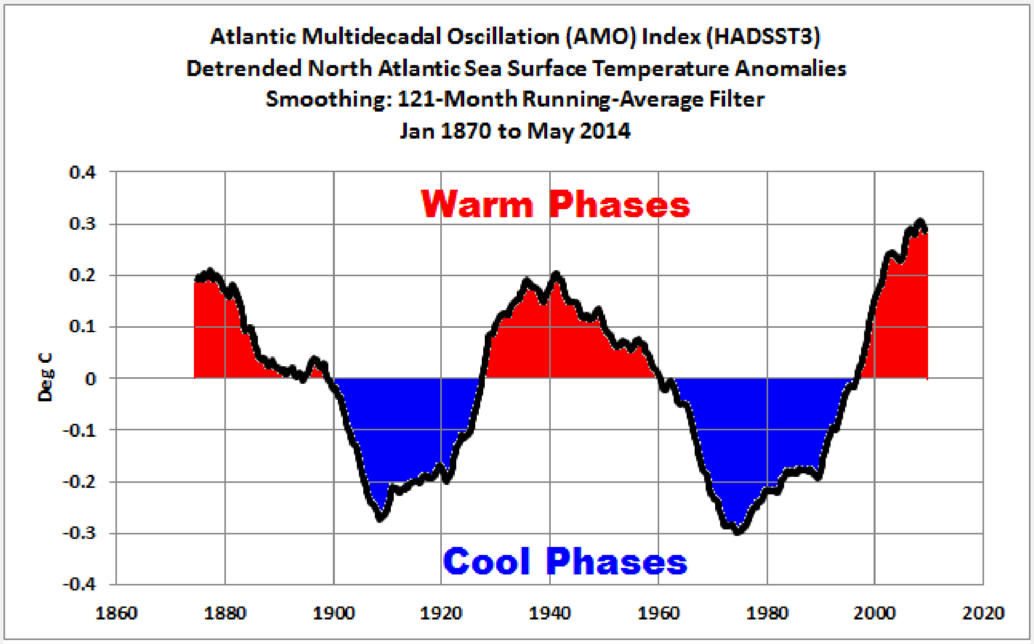


Figure 3.3-3

I've also color-coded the periods when the smoothed Atlantic Multidecadal Oscillation Index data are above and below zero; that is, the "warm" and "cool" phases. Those warm and cool phases of the Atlantic Multidecadal Oscillation are referred to by climate scientists in studies of hurricane frequency and in studies of rainfall and drought. Those periods, however, do not represent when the Atlantic Multidecadal Oscillation enhances or suppresses global warming. We'll discuss that in a few moments.   There are a few other things to discuss.

NOAA uses a 121-month running-average filter for their Atlantic Multidecadal Oscillation Index, so I've also used one for the filtering in this chapter. Each data point represents the average of 121 months (basically 10 years) of data. And the data points are centered on the 61st months. That is, the first data point is at January 1875, and it represents the average of the data from January 1870 to January 1880; the second data point is at February 1875, and it captures the average from February 1870 to February 1880; and so on every month through May 2009, which represents the average from May 2004 through May 2014.

THE ATLANTIC MULTIDECADAL OSCILLATION EXTENDS FARTHER THAN THE COORDINATES USED BY NOAA

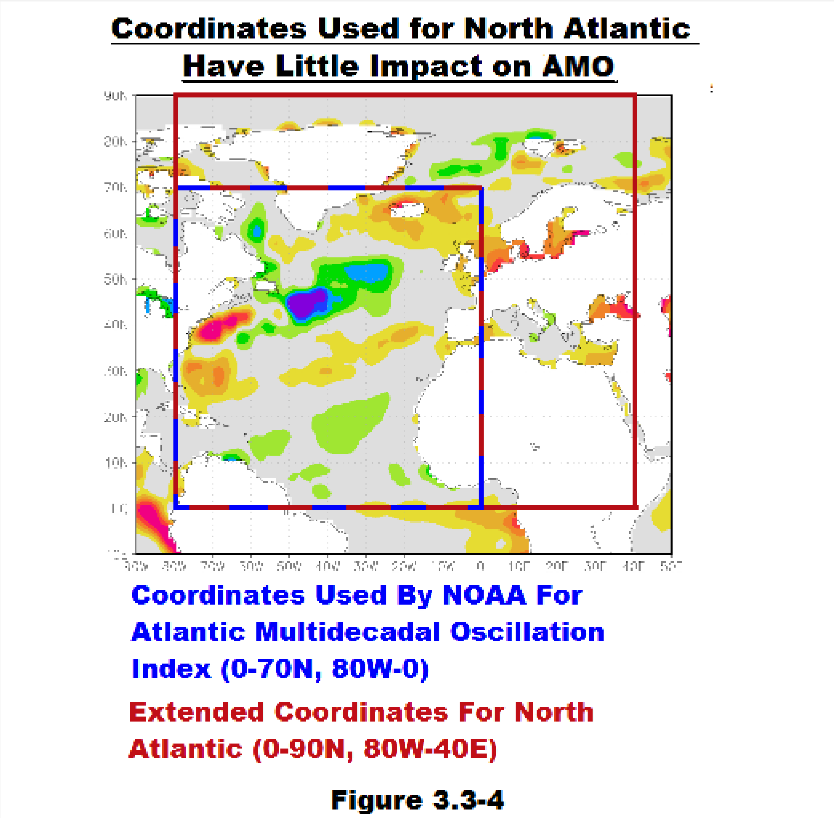


Figure 3.3-4

The coastlines of the North Atlantic are quite irregular, as they are in all of the ocean basins. Even so, the coordinates used by NOAA (0-70N, 80W-0) for their Atlantic Multidecadal Oscillation Index capture a major portion of the North Atlantic. See Figure 3.3-4. As you'll note, the coordinates used by NOAA for the North Atlantic capture a part of the Arctic Ocean, if we assume the Arctic Ocean extends as far south as 65N. As you'll also note there are small portions missed, like much of the Gulf of Mexico and part of the Caribbean which are considered portions of the North Atlantic. But, all in all, the coordinates used by NOAA include most of the North Atlantic.

We can extend those coordinates out to include the Mediterranian and Black Seas and the rest of the part of the Arctic Ocean that is included in the coordinates of 0-90N, 80W-40E. As shown in Figure 3.3-5, there is little difference in the two representations of the North Atlantic data. The two datasets correlate almost perfectly, with a correlation coefficent of 0.97, meaning most of the wiggles align. The long-term trends are also nearly identical.

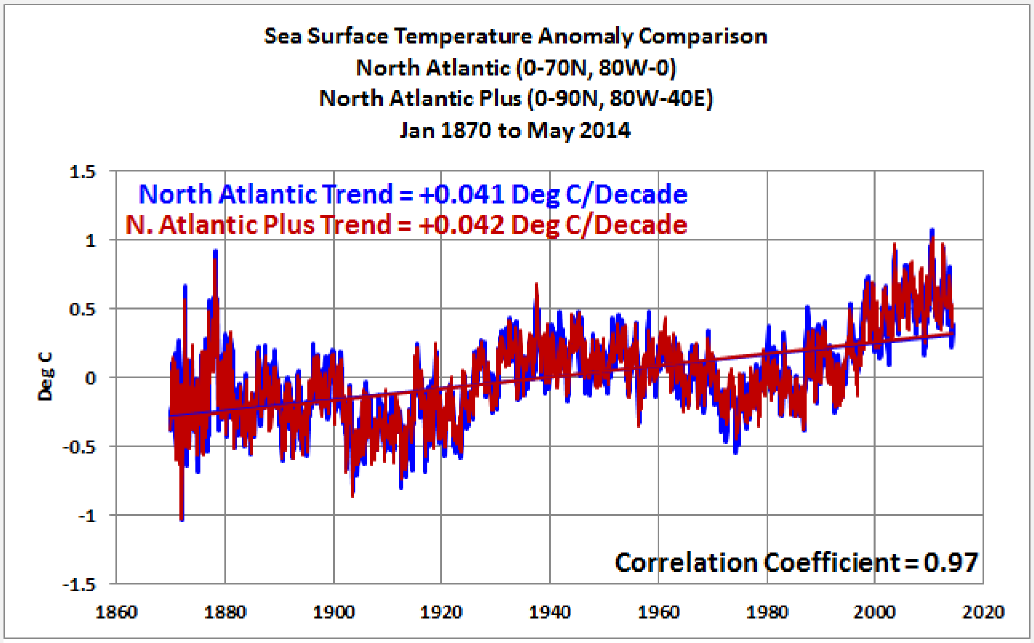


Figure 3.3-5

The reason I presented that comparison is, if you were to study the numerous papers about the Atlantic Multidecadal Oscillation, you'll often see different coordinates used to represent the multidecadal variations in the North Atlantic. The vast majority of them will present the same multidecadal variations. They can differ slightly depending on the dataset used (HADSST3, HADISST or ERSST.v4), and as shown in Figure 3.3-6, the differences are nothing to be concerned about for general discussions. But…

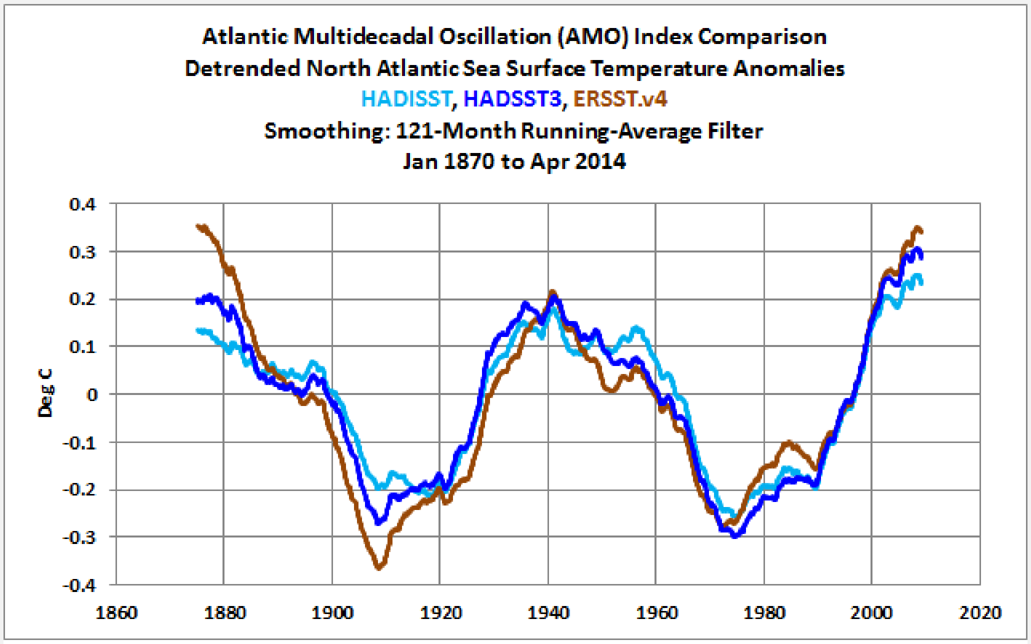


Figure 3.3-6

…due to the differences, if you're studying the effect of the Atlantic Multidecadal Oscillation on global sea surface temperatures or global land-plus-sea surface temperatures it is best to use an Atlantic Multidecadal Oscillation Index based on the temperature dataset you're studying. That sounds obvious, but you'll often see papers relying on the NOAA Atlantic Multidecadal Oscillation Index, which uses Kaplan sea surface temperature data, for an evaluation of GISS, NOAA or UKMO global land+ocean surface temperature data, which do not use Kaplan sea surface temperature data.

THE ATLANTIC MULTIDECADAL OSCILLATION ALSO EXTENDS INTO THE TROPICAL SOUTH ATLANTIC

Figure 3.3-7 presents the trends (Deg C/decade) of the sea surface temperature anomalies of the Atlantic Ocean, for three multidecadal periods, from the Southern Ocean (left) to the Arctic Ocean (right), on a latitude-average (zonal-means) basis. The year 1975 is a commonly used breakpoint that separates the mid-20th Century cooling period in global land-plus-sea surface temperatures and the warming peiod that happened afterwards. And that coincides roughly with the breakpoint shown in the smoothed Atlantic Multidecadal Oscillation Index data above in Figures 3.3-3 and 3.3-6.

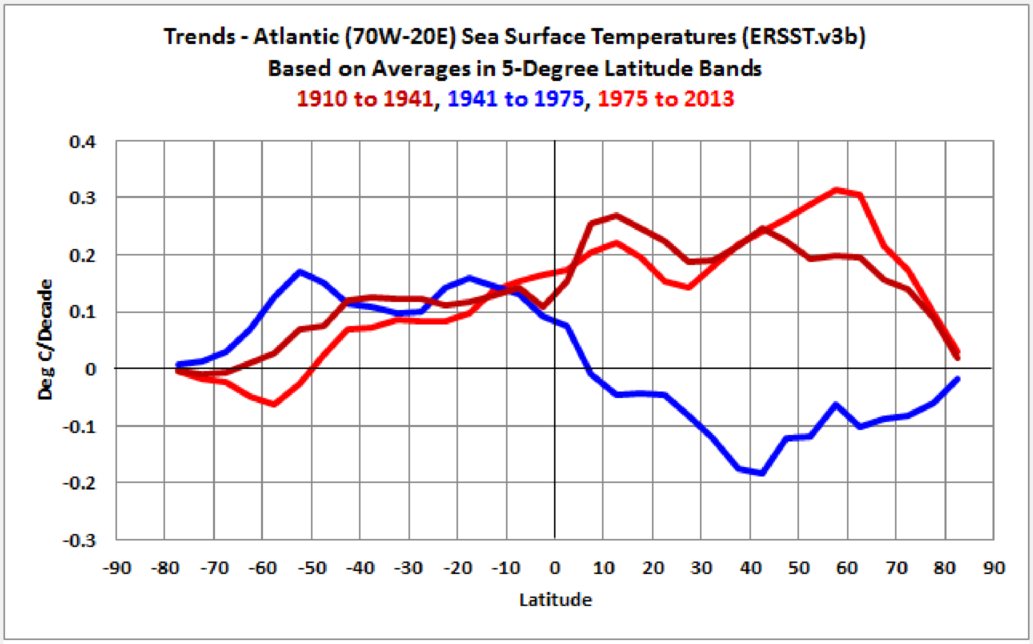


Figure 3.3-7

The initial warming period of that index extends from about 1910 to just after 1940, say 1941. And the mid-20th Century cooling period occurred between them: 1941 to 1975. We could shift those breakpoints a year or two in either direction and it would have little impact on this part of the presentation. The units of the vertical axis (y-axis) are degrees C per decade (Deg C/decade), and they are based on the linear trends during those periods, for the 5-degree latitude bands. The North Atlantic is to the right of zero (the equator) and the South Atlantic is to the left. I've presented NOAA's recently obsoleted ERSST.v3b sea surface temperature data in Figure 3.3-8. The ERSST.v3b data is infilled so there are no missing data during months when a 5-degree latitude band contains no source data. (With HADSST3, on the other hand, the data are not infilled, and, as a result, when they data are broken down into small subsets, there are many short-term periods with missing data, especially in the high latitudes of the South Atlantic. That makes it difficult to work with for a trend analysis like this.)

As shown, the cooling period trend (1941 to 1975) diverges from the trends for the two warming periods just south of the equator. If we switch to the another infilled long-term sea surface temperature dataset, HADISST, the point at which the trends diverge shifts farther south. See Figure 3.3-8.

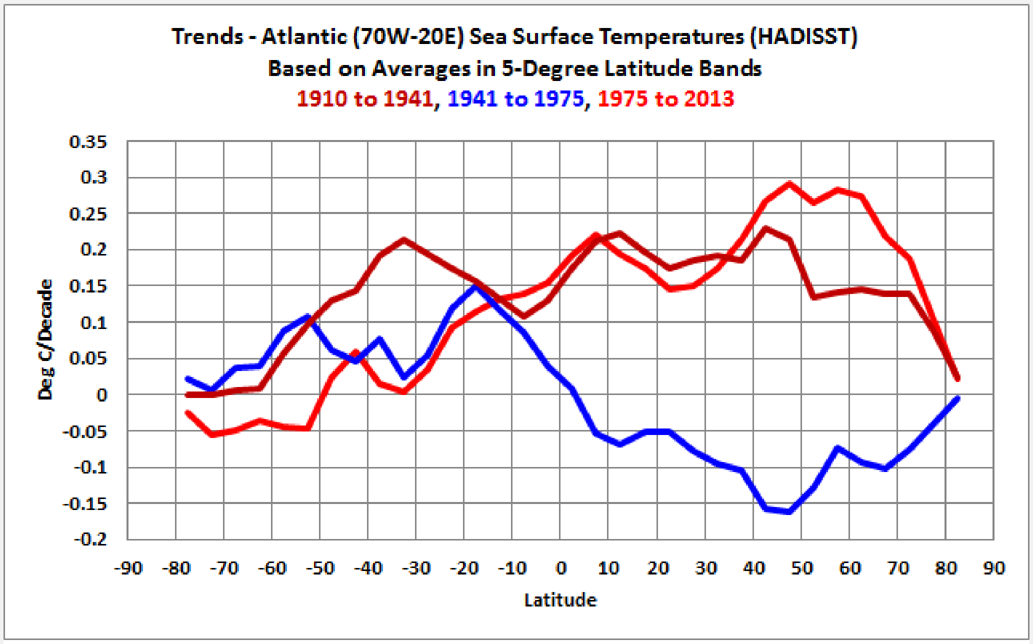


Figure 3.3-8

What is also important to note with both sea surface temperature datasets is, the peak warmings and coolings do not necessarily occur at the same latitudes of the North Atlantic, meaning the warming during one period may not offset the cooling during another and vice versa. And because land surface temperatures in the Northern Hemisphere are impacted by the variations in the sea surface temperatures of the North Atlantic, those variations in where the North Atlantic are warming and cooling will impact where land surface temperatures warm and cool in the Northern Hemisphere.

DIFFERENT METHODS OF PRESENTING THE ATLANTIC MULTIDECADAL OSCILLATION

Detrending North Atlantic sea surface temperature anomalies is one way to show the Atlantic Multidecadal Oscillation (AMO). Another way is to subtract global sea surface temperature data from those of the North Atlantic, which was suggested by Trenberth and Shea (2006) Atlantic hurricanes and natural variability in 2005. They wrote (THC in the quote stands for Thermohaline Circulation):

> *The main difficulty with the traditional AMO index is that it is not possible to discriminate between variations arising from the THC and other phenomena with North Atlantic origins, and global anthropogenic changes. In particular, the recent warming of North Atlantic SSTs is known to be part of a global (taken here to be 60_N to 60_S) mean SST increase ~~(Figure 2)~~. [Their Illustration number.] While detrending [Knight et al., 2005] the AMO series helps remove part of this signal, the SST changes are not simply linear and a linear trend has no physical meaning. To deal with purely Atlantic variability, it is highly desirable to remove*

> *the larger-scale global signal that is associated with global processes, and is thus related to global warming in recent decades [Meehl et al., 2004; Barnett et al., 2005; Hansen et al., 2005]. Accordingly, the global mean SST has been subtracted to derive a revised AMO index ~~(Figure 3)~~.* [Their Illustration number.]

The results of two methods are compared in Figure 3.3-9.

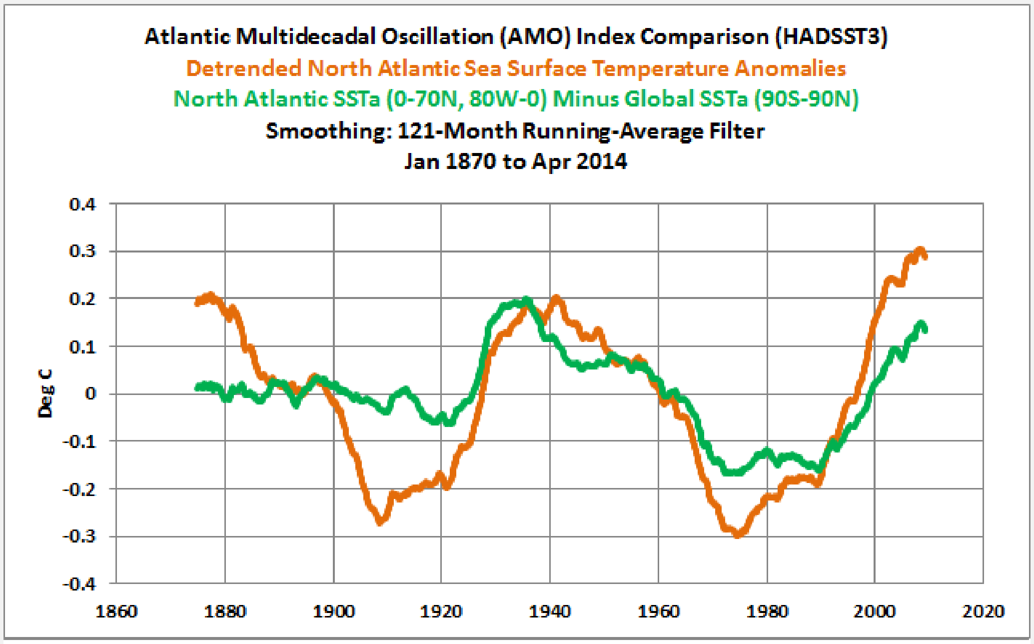


Figure 3.3-9

If you're interested in the difference between the North Atlantic data and the global data, then Trenberth and Shea (2006) method for presenting the Atlantic Multidecadal Oscillation is the one you'd choose. However, the global data includes the North Atlantic data, so when the global data are subtracted from the North Atlantic data, a portion of the North Atlantic data are being subtracted from the North Atlantic data, and that defeats the intent to some extent. Therefore, if you're interested in the additional variations in the North Atlantic sea surface temperatures above and beyond those of all the other ocean basins combined, then the ideal method to capture the additional variability of the North Atlantic would be to subtract the combined sea surface temperature data for all of the other ocean basins (the global data without the North Atlantic data) from the North Atlantic data.

There is a second point to consider when using the Trenberth and Shea method. There are subtle differences between the sea surface temperature datasets, and those differences can change the appearance of the Atlantic Multidecadal Oscillation, when the Atlantic Multidecadal Oscillation is determined by subtracting the global data from the North Atlantic data. As shown in Figure 3.3-10, they provide surprisingly different results, especially during the mid-20th Century "warm" period and the early cool period.

NOAA's ERSST.v4 data (brown curve) peak noticeably higher than the other two datasets in the 1930s, and they also decline more initially until about 1910. The UKMO HADSST3 data show a peak in the 1930s, without the secondary surge in the 1950s. The other UKMO sea surface temperature dataset (HADISST) shows a lesser peak in the 1930s, making the secondary peak in the 1950s comparable in size.

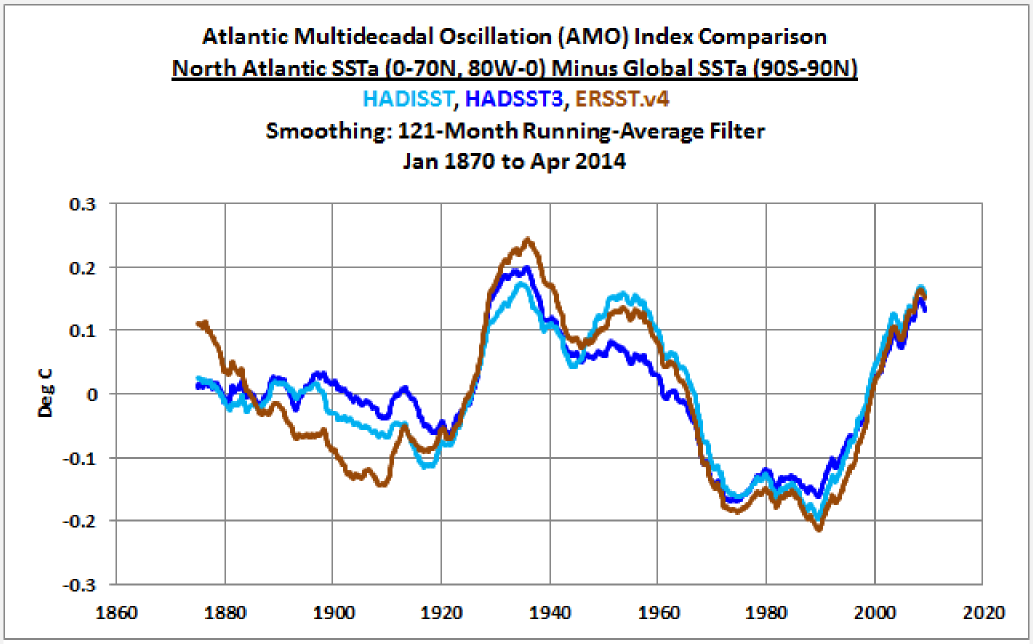


Figure 3.3-10

There is something else to consider. And this can be seen when we compare the results of the two methods used to create an Atlantic Multidecadal Oscillation Index. Refer to again to Figure 3.3-9 (two illustrations ago). The Atlantic Multidecadal Oscillation Index created by detrending the North Atlantic sea surface temperature data has the greater variability. That should be expected, because the global data also include multidecadal variations (and some of them come from the North Atlantic). The other thing that stands out is the version created by subtracting the global data from the North Atlantic data loses most of its variability before 1930. And that's common for all three long-term sea surface temperature datasets. See Figure 3.3-10.

There are a few possible causes for this:

- The North Atlantic and the other ocean basins were in synch during that period.
- The North Atlantic is the best sampled of all ocean basins. As we go back in time, especially before the 1940s, the North Atlantic observations begin to dominate the global data more and more.

So, exercise caution when using the method suggested by Trenberth and Shea (2006) for creating an Atlantic Multidecadal Oscillation Index.

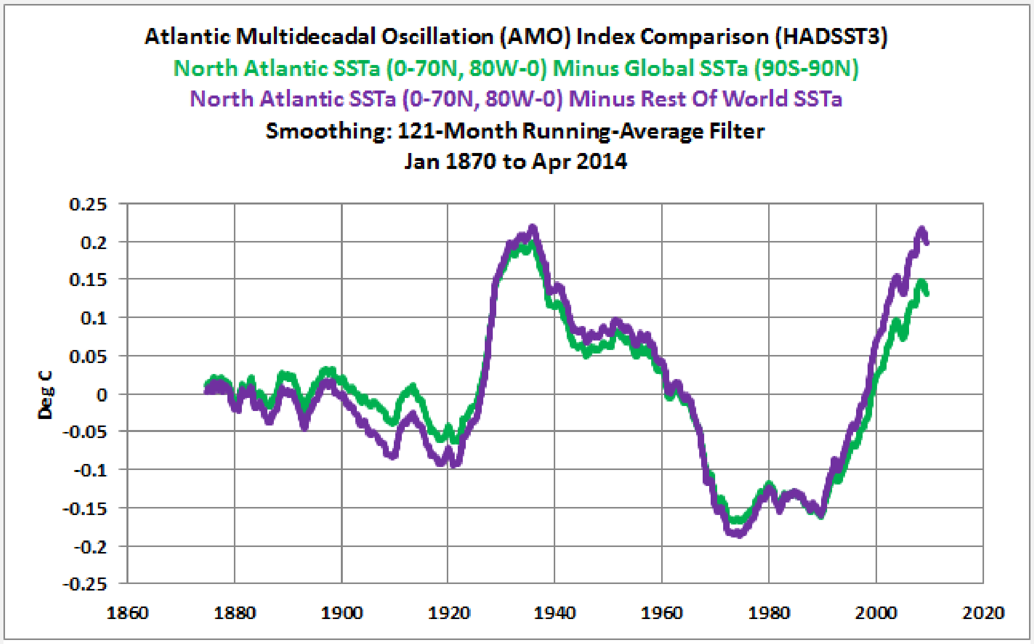


Figure 3.3-11

Another method, as noted earlier, is to first remove the North Atlantic data from the global data, and then subtract the remainder (which represents the sea surface temperature data for all the other basins) from the North Atlantic data. That leaves the additional variations of the North Atlantic above and beyond those of the other ocean basins. Those results (the purple curve identified as the North Atlantic data minus the data for the rest-of-the-world sea surface temperature anomalies) are compared to the Trenberth and Shea (2006) method in Figure 3.3-11. The surface area percentages of the global oceans are listed in the NOAA National Geophysical Data Center webpage Volumes of the World's Oceans from ETOPO1. That served as the reference for the North Atlantic covering 11.5% of the surface of the global oceans. The North Atlantic data were then scaled by 11.5% before subtracting them from the global data to create the data for rest-of-the-world.

There are a few surprising similarities and differences between the Trenberth and Shea (2006) method and the method of creating an Atlantic Multidecadal Oscillation Index by subtracting the rest-of-the-world sea surface temperature data from the North Atlantic data. The most important difference occurs during the late warming period from the mid-1970s to present. The method proposed by Trenberth and Shea (2006) suppressed that contribution by a noticeable amount during the recent warming period. That's the period when the climate-science community says only greenhouse gases can explain the global warming. Data contradict that climate model-based assumption. Data reveal that the multidecadal variations of the sea surface temperatures of the North Atlantic also contributed. We'll further discuss the contribution of the Atlantic Multidecadal Oscillation to the recent warming period in a few moments.

THE PERIODS WHEN NORTH ATLANTIC SEA SURFACE TEMPERATURES ENHANCED OR SUPPRESSED GLOBAL WARMING

As presented earlier in this chapter, the NOAA Frequently Asked Questions About the *Atlantic Multidecadal Oscillation (AMO)* webpage notes that the additional variability of the sea surface temperatures of the North Atlantic (the Atlantic Multidecadal Oscillation – AMO) can contribute to or suppress global warming. They wrote:

> *In the 20th century, the climate swings of the AMO have alternately camouflaged and exaggerated the effects of global warming, and made attribution of global warming more difficult to ascertain.*

Referring to the color-coded Figure 3.3-3 above, we also discussed how the "warm" and "cool" phases of the Atlantic Multidecadal Oscillation do not represent the periods when the Atlantic Multidecadal Oscillation enhances or suppresses global warming. In reality, the Atlantic Multidecadal Oscillation enhances global warming when the Atlantic Multidecadal Oscillation Index is rising, and the Atlantic Multidecadal Oscillation suppresses global warming when the Atlantic Multidecadal Oscillation Index is falling. This relationship is visible if we compare the Atlantic Multidecadal Oscillation Index (detrended version) to global sea surface temperature anomalies, Figure 3.3-12.

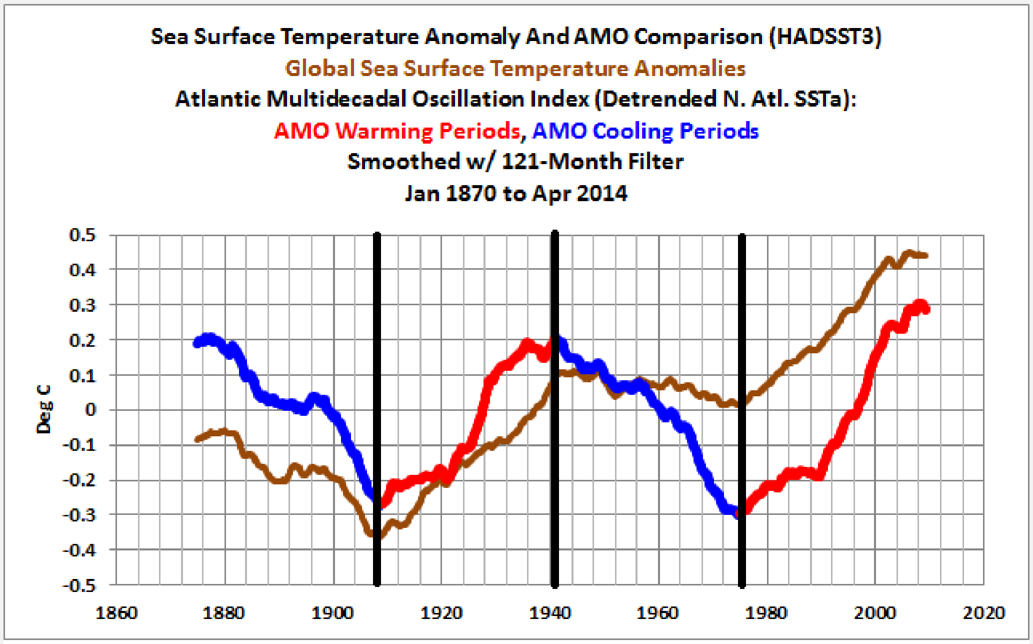


Figure 3.3-12

In Figure 3.3-12, both datasets have been smoothed with 121-month running-average filters. The black vertical lines separate the warming from the cooling periods, and they're based solely on the approximate (apparent) breakpoints in the global sea surface temperature data. For this graph, HADSST3 sea surface temperature data were used.

Keep in mind that the Atlantic Multidecadal Oscillation Index is a detrended dataset. To get a better idea of when the Atlantic Multidecadal Oscillation actually enhances or suppresses global warming, it is best to compare North Atlantic sea surface temperature anomalies to the global sea surface temperature data. See Figure 3.3-13. Once again, HADSST3 data are being presented, the data are smoothed with 121-month filters and I've added the black vertical lines at the approximate warming and cooling breakpoints in the global data.

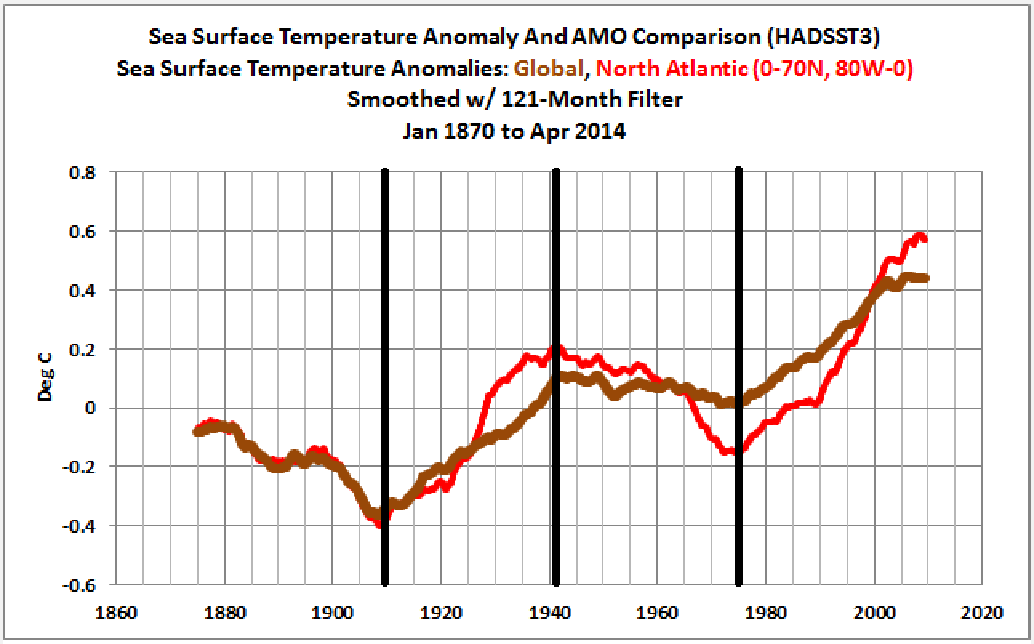


Figure 3.3-13

During the early cooling period, the North Atlantic data dropped at about the same rate as the global data, so the North Atlantic sea surface temperatures did not enhance or suppress that cooling. From 1910 to about 1920, the data show the surfaces of the North Atlantic warmed more slowly than the global data, so the North Atlantic was suppressing the global warming during that initial part of the early warming period. Then, from 1920 to about 1940, the surfaces of the North Atlantic warmed at a much faster rate than they did globally. This overcame the initial deficit and allowed the North Atlantic to enhance the global warming for the entire early warming period of 1910 to 1940.

We see similar responses during the mid-20th Century cooling period and the late warming period. That is, the North Atlantic sea surface temperatures run in parallel with the global data for the initial 10 to 15 years of those periods. It's only after those initial periods that the North Atlantic either cools or warms more rapidly than the global data, which then enhances the cooling or warming.

Figure 3.3-14 is similar to the previous graph, but in it, I've added the Atlantic Multidecadal Oscillation Index, the version based on subtracting the global sea surface temperature data from the North Atlantic data. I've provided it to show the relationship of that version of the Atlantic Multidecadal Oscillation Index to the two sources.

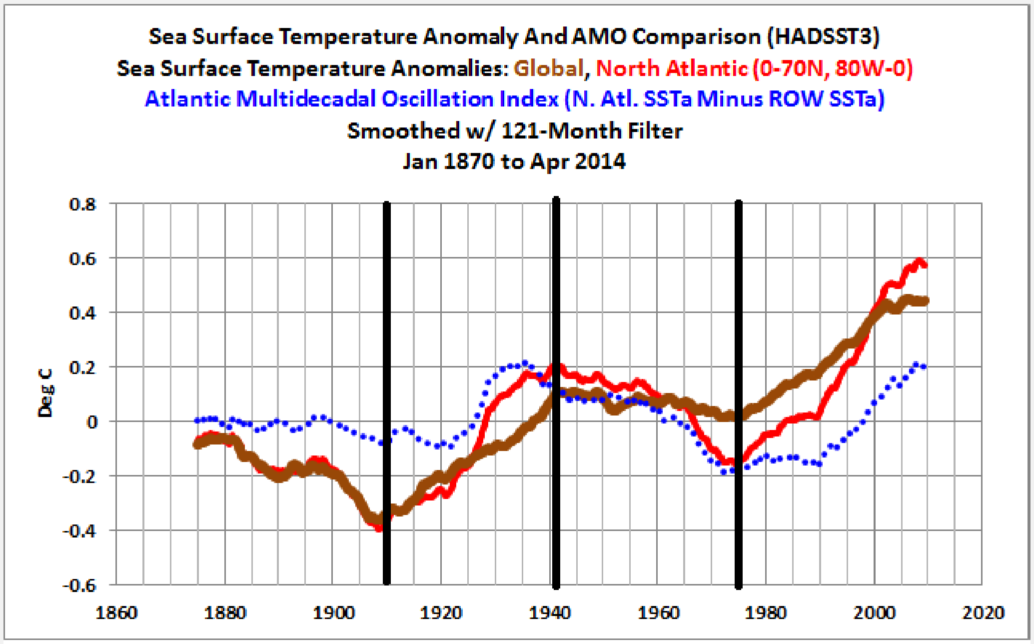


Figure 3.3-14

One last comment under this heading: Recently we've been hearing the battle cry, *Wait until the AMO turns negative*, or something to that effect. Those persons making the statement are referring to the detrended version of the Atlantic Multidecadal Oscillation Index, and they're assuming when the Atlantic Multidecadal Oscillation turns negative, the North Atlantic is somehow providing global cooling. But as we've discussed, the Atlantic Multidecadal Oscillation does not impact global surface temperatures that way.

Let's consider the sea surface temperatures for the rest of the world (other than the North Atlantic) and the three modes in which they can be. The North Atlantic has subtly different impacts globally during those three modes, which have nothing to do with the AMO being in the positive or negative phases shown in Figure 3.3-3.

> **Warming** – If the sea surfaces of the rest of the global oceans are warming and surface of the North Atlantic is warming at a faster rate, then the North Atlantic is enhancing the warming of the global sea surfaces. If the surfaces of the rest of the oceans are warming but the surface of the North Atlantic is warming at a

slower rate, then the North Atlantic is suppressing ocean surface warming globally.

Cooling – Conversely, when the sea surfaces of the rest of the global oceans are cooling and surface of the North Atlantic is cooling faster, then the North Atlantic is enhancing the cooling of the global sea surfaces. Likewise, if the surfaces of the rest of the oceans are cooling but the surface of the North Atlantic is cooling at a slower rate, then the North Atlantic is suppressing the surface cooling of the global oceans.

No Warming or Cooling – There are periods when the surfaces of the rest of the global oceans are neither warming nor cooling. If the surface of North Atlantic is warming, then it is the only contributor to the warming of the ocean surfaces, and vice versa if the surface of the North Atlantic is cooling.

The detrended version of the Atlantic Multidecadal Oscillation with its warm and cool phases (shown in Figure 3.3-3) does not reflect any of those modes because (1) it does not account for the warming or cooling mode of the rest of the ocean surfaces and (2) the detrended data do not tell us if the North Atlantic is actually warming or cooling.

WHAT IMPACT DOES THE ATLANTIC MULTIDECADAL OSCILLATION HAVE ON NORTHERN HEMISPHERE SURFACE TEMPERATURES?

It was noted a few times in this chapter that the Atlantic Multidecadal Oscillation has a strong influence on the land surface temperatures of the Northern Hemisphere. There is a recent climate model-based study that indicates that all of the multidecadal variations in the land-plus-ocean surface temperatures of the Northern Hemisphere can be explained as responses to the Atlantic Multidecadal Oscillation. That 2007 paper is Can the Atlantic Ocean drive the observed multidecadal variability in Northern Hemisphere mean temperature? by Zhang et al. The abstract of Zhang et al. (2007) reads (my boldface):

> *While the Northern Hemisphere mean surface temperature has clearly warmed over the 20th century due in large part to increasing greenhouse gases, this warming has not been monotonic. The departures from steady warming on multidecadal timescales might be associated in part with radiative forcing, especially solar irradiance, volcanoes, and anthropogenic aerosols. It is also possible that internal oceanic variability explains a part of this variation.* ***We report here on simulations with a climate model in which the Atlantic Ocean is constrained to produce multidecadal fluctuations similar to observations by redistributing heat within the Atlantic, with other oceans left free to adjust to these Atlantic perturbations. The model generates multidecadal variability in Northern Hemisphere mean temperatures similar***

> ***in phase and magnitude to detrended observations. The results suggest that variability in the Atlantic is a viable explanation for a portion of the multidecadal variability in the Northern Hemisphere mean temperature record.***

In other words, the modelers reproduced the multidecadal variations in the detrended sea surface temperatures of the North Atlantic (the Atlantic Multidecadal Oscillation) using a specialized model for this experiment. They then studied the detrended modeled surface temperatures of the entire Northern Hemisphere (land plus ocean surfaces) that occurred in response to the multidecadal variations in the sea surface temperatures of the North Atlantic. They found the model reproduced the observed timing and <u>extent</u> of the multidecadal variations in the detrended Northern Hemisphere land-plus-ocean surface temperatures. They use the word "portion" in the closing sentence, because, while the Atlantic Multidecadal Oscillation can explain the variations that occur over multidecadal timeframes, it does not explain the long-term warming trend of the Northern Hemisphere surface temperatures. Nonetheless, it is very important.

In their Conclusion and Discussion, Zhang et al. (2007) note:

> *Our results reinforce the result of Knight et al. [2005] that Atlantic multidecadal variability can potentially play an important role in the evolution of Northern Hemisphere mean temperatures. Our methodology is different from Knight et al.; rather than focusing on a freely running coupled model, we manipulate the heat redistribution in the Atlantic Ocean so as to match the observed time series of detrended Atlantic temperatures, and then find that the model matches the detrended northern hemisphere mean surface temperatures as well.*

Zhang et al. (2007) then added a qualification, a disclaimer of sorts, in their closing paragraph (my boldface):

> ***Nothing in our results suggests that the underlying long-term warming trend has a significant component due to internal Atlantic variability.*** *In ACE, the southern hemispheric variability is smaller than the northern hemispheric variability, and the North and South Atlantic variability are out of phase. In contrast, the observed century-long warming trends are comparable in magnitude in the two hemispheres and are of the same sign in the North and South Atlantic. A comparison of observations and modeling results of the long-term warming trends in the fully coupled model are described by Knutson et al. [2006].* ***Our results are directed towards understanding the low-frequency departures of the Northern Hemisphere mean temperature from a uniform warming trend.***

Zhang et al. (2007) are very clear that the Atlantic Multidecadal Oscillation does not explain the long-term warming trend in Northern Hemisphere land-plus-ocean surface temperatures, but they are also quite clear that the Atlantic Multidecadal Oscillation can explain the multidecadal variations in the surface temperatures of the Northern Hemisphere. Unfortunately, they did not explain why that's important.

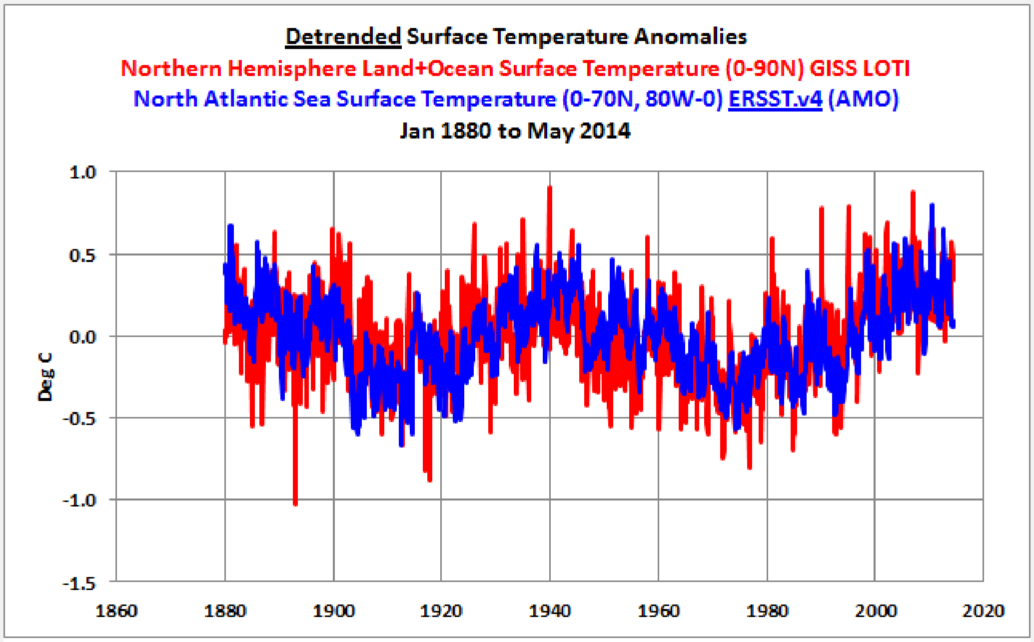


Figure 3.3-15

Let's look at the land-plus-ocean surface temperatures for the Northern Hemisphere since 1880 and compare them to the sea surface temperatures of the North Atlantic. For this example, we'll use a different surface temperature dataset than the one used by Zhang et al (2007). They used a version of the UKMO CRUTEM land surface air temperature data that is no longer available, along with the UKMO HADISST sea surface temperature data. For the sake of simplicity, we'll use the latest version of the GISS Land Ocean-Temperature Index (LOTI) data for the Northern Hemisphere and the NOAA ERSST.v4 sea surface temperature data for the North Atlantic. Both are available through the KNMI Climate Explorer. In Figure 3.3-15, I've detrended both datasets, and I've left them in monthly form.

The multidecadal variations in the detrended Northern Hemisphere land-plus-ocean surface temperatures mimic the multidecadal variations in the detrended sea surface temperature anomalies of the North Atlantic, and according to Zhang et al. (2007) it's the naturally occurring variations North Atlantic sea surface temperatures that are driving the variations in the land-plus-ocean temperatures of the Northern Hemisphere.

Now let's explain why that's important. The long-term warming rate of the land-plus-ocean surface temperatures of the Northern Hemisphere is only about 0.07 deg

C/decade (about 0.125 deg F/decade). Refer to Figure 3.3-16. I've also included the detrended Northern Hemisphere land-plus-ocean surface temperature data in the illustration. Note how during the late warming period (which started around 1975) that the warming rate of the detrended data represents a major portion of the warming rate of the "raw" (undetrended) data.

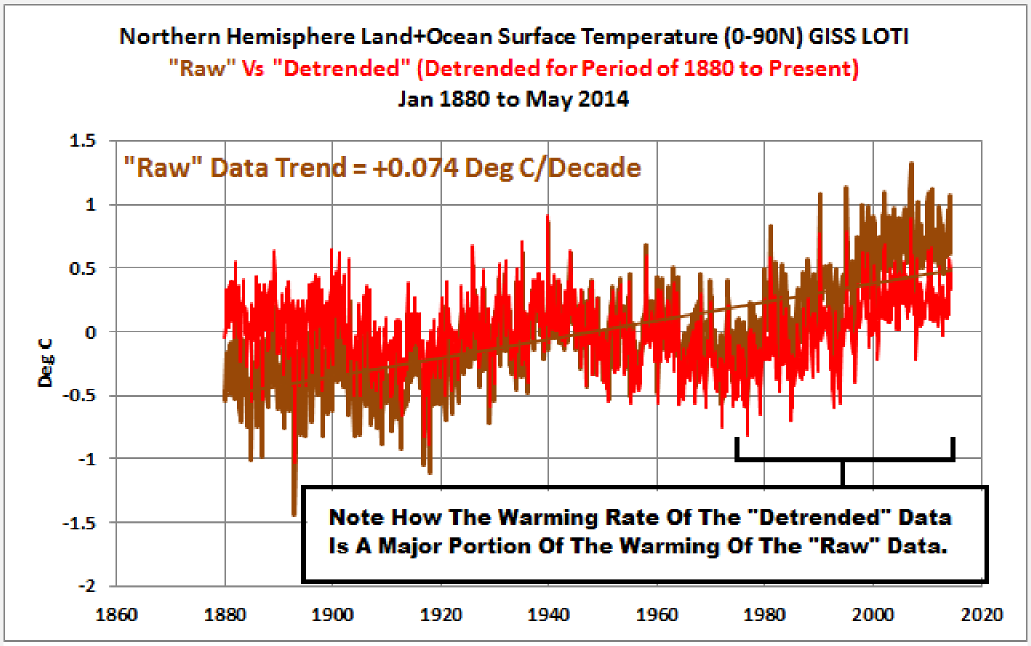


Figure 3.3-16

Based on the linear trends of the "raw" and "detrended" Northern Hemisphere land-plus-ocean surface temperature data, the warming rate of the "detrended" data since 1975 is about 70% of the warming rate of the "raw" (un-detrended) data. See Figure 3.3.-17. That is, the linear trend of the "raw" data since 1975 is about 0.24 deg C/decade (about 0.43 deg F/decade), while the linear trend of the "detrended" data, which as you'll recall can be explained as a natural response to the Atlantic Multidecadal Oscillation, has a warming rate of 0.17 deg C/decade (about 0.31 deg F/decade) over the same time period. Or to phrase it differently, the Atlantic Multidecadal Oscillation can explain about 70% of the surface warming in the Northern Hemisphere since 1975. We used basic math and simple logic to show that a naturally occurring ocean processes, not man-made greenhouse gases, were responsible for most of the warming in the Northern Hemisphere since 1975.

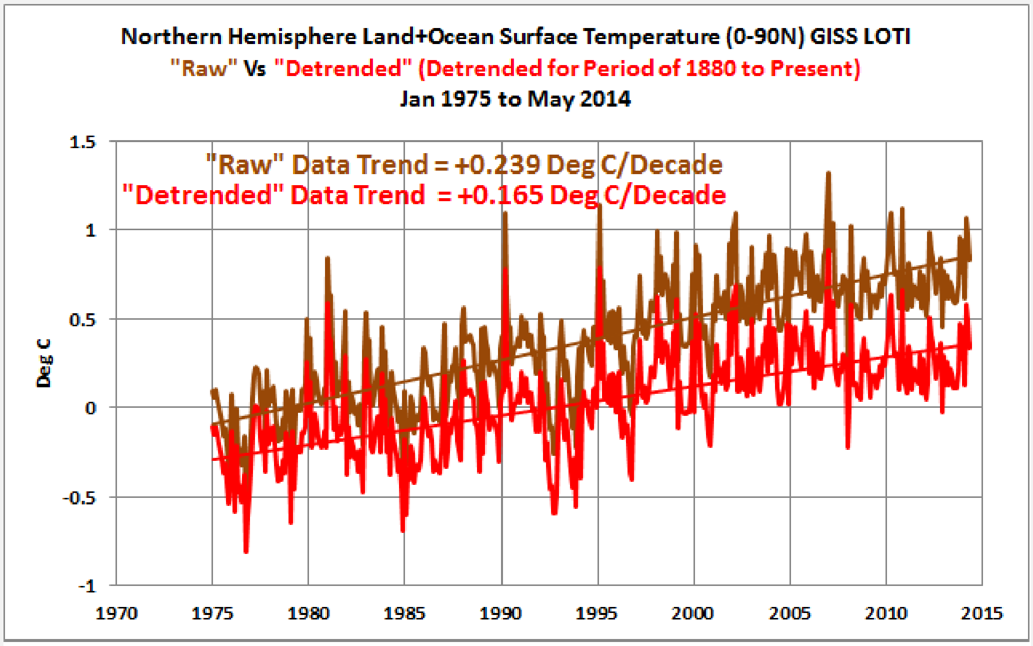


Figure 3.3-17

That confirms the discussion of the Atlantic Multidecadal Oscillation found at the website RealClimate. As you'll recall, RealClimate is a blog run by a group of high-profile climate scientists. On their Atlantic Multidecadal Oscillation ("AMO") webpage, RealClimate writes (my boldface):

> *A multidecadal (50-80 year timescale) pattern of North Atlantic ocean-atmosphere variability whose existence has been argued for based on statistical analyses of observational and proxy climate data, and coupled Atmosphere-Ocean General Circulation Model ("AOGCM") simulations.* ***This pattern is believed to describe some of the observed early 20th century (1920s-1930s) high-latitude Northern Hemisphere warming and some, but not all, of the high-latitude warming observed in the late 20th century.*** *The term was introduced in a summary by Kerr (2000) of a study by Delworth and Mann (2000).*

70% of the warming of Northern Hemisphere surface temperatures is definitely "…some, but not all…"

But there are members of the climate science community who do not like that basic reality, so they use some smoke and mirrors in an effort to downplay it. We'll discuss that in a little while.

Now, I'm not saying that the Atlantic Multidecadal Oscillation, according to the data, is responsible for 70% of the global warming since 1975, just the Northern Hemisphere. While there is some bleed over of the Atlantic Multidecadal Oscillation into the Southern Hemisphere, you'd likely be safe to say that the Atlantic Multidecadal Oscillation, again according to the data, is responsible for about 35% of the global warming since 1975, roughly one-third.

Climate scientists continue to argue the Atlantic Multidecadal Oscillation is forced by man-made greenhouse gases and aerosols. But we'll show later in this chapter that climate models contradict that assumption. That is, as we'll see later in this book, the climate models used by the IPCC for projections of future climate cannot simulate the Atlantic Multidecadal Oscillation. In fact, the climate models were tuned to the naturally occurring upswing in the surface temperatures since 1975, without considering that the cooling phase of the Atlantic Multidecadal Oscillation would eventually cause surface temperatures in the Northern Hemisphere to plateau and cool for a few decades. Then, after a few more decades, the warming phase would add to the warming again, etc., cycling back and forth along a long-term warming rate of only 0.07 deg C/decade (about 0.125 deg F/decade).

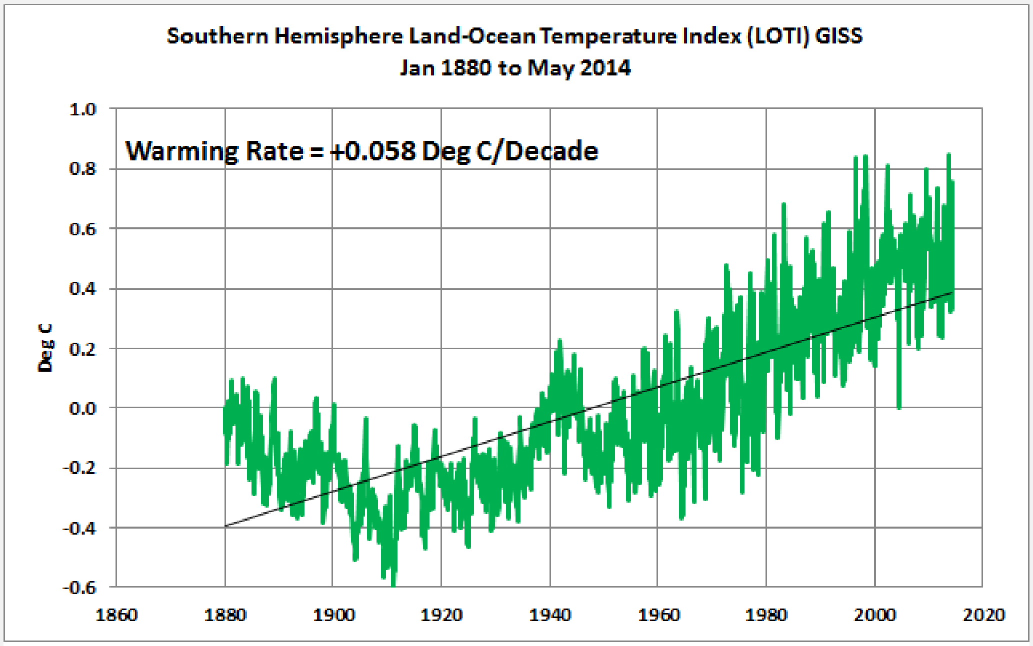


Figure 3.3-18

And if you're wondering, the long-term warming rate of the Southern Hemisphere land-plus ocean data is only 0.058 deg C/decade (about 0.1 deg F/decade). See Figure 3.3-18.

WHAT CAUSES THE VARIATIONS IN THE SEA SURFACE TEMPERATURES OF THE NORTH ATLANTIC?

Climate scientists don't know for sure, because there has only been about a decade of reasonably accurate measurements of subsurface temperatures and salinity in the North Atlantic.

What they do know: Data show that sea surface temperatures in the North Atlantic can increase at rates that exceed the long-term linear trend for some multidecadal periods, and during other periods, the sea surface temperatures can actually flatten and cool. The full "cycles" last for approximately 60 years…sometimes 50 years, sometimes 80 years. The climate science community also knows that thermohaline circulation exists in the North Atlantic; that is, cold, high-salt-content waters drop from the surface to the deep ocean layers at the high-latitudes of the North Atlantic.

There are, therefore, hypotheses (speculations) that variations in the rates of thermohaline circulation drive the Atlantic Multidecadal Oscillation. Unfortunately, subsurface temperature and salinity data to depths of 2000 meters have only existed from the ARGO floats for a little more than one decade. One decade of reasonably complete sampling provides little information about processes that can take 5 to 8 decades.

As you'll recall, Dr. Raymond Schmitt of the Woods Hole Oceanographic Institution testified before congress back in 2000 when the climate science community was looking for funding for the ARGO program. His statement at that time will shed some light on the problems facing the climate science community with respect to processes such as the Atlantic Multidecadal Oscillation.

> *These new technologies will give us the data we need **to begin** to decipher the complex climate phenomena we know to be operating in the ocean.*

And after a decade of data from the ARGO floats we are still only beginning to understand a process that can take 5 to 8 decades to complete. Then the question will be, was that a typical cycle or an unusual cycle? Maybe in a few more centuries, oceanographers and climate scientists might have answers.

Obviously, the climate science community is looking for answers now, so they prepare specialized climate models to study specific processes. One such study was Knight et al. (2005) A signature of persistent natural thermohaline circulation cycles in observed climate. It has become an often-cited paper for what drives that Atlantic Multidecadal Oscillation. Their abstract reads (my boldface):

> *Analyses of global climate from measurements dating back to the nineteenth century show an 'Atlantic Multidecadal Oscillation' (AMO) as a leading large-scale pattern of multidecadal variability in surface temperature. Yet it is not possible to determine whether these fluctuations are genuinely oscillatory from the relatively short observational record alone. Using a 1400 year climate model calculation, we are able to simulate the observed pattern and amplitude of the AMO. The results imply the AMO is a genuine quasi-periodic cycle of internal climate variability persisting for many centuries, and is related to variability in the*

> *oceanic thermohaline circulation (THC). This relationship suggests we can attempt to reconstruct past THC changes, and we infer an increase in THC strength over the last 25 years.* ***Potential predictability associated with the mode implies natural THC and AMO decreases over the next few decades independent of anthropogenic climate change.***

"The results imply…" "This relationship suggests…" *Imply* and *suggest* are not words that indicate confidence. Knight el al. (2005) are basically saying that, yes, variations in thermohaline circulation **could be** the cause of the Atlantic Multidecadal Oscillation.

But there are other factors that can cause the North Atlantic to warm over multidecadal periods:

- The sea surface temperatures of the North Atlantic do not always respond proportionally to El Niño and La Niña events; that is, the response of the surface temperatures of the North Atlantic to strong El Niño events is greater than the response to the La Niña events that trail them. That disproportionate response indicates the sea surface temperatures of the North Atlantic will warm during multidecadal periods when there are strong El Niño events. Not surprisingly, there were a couple of very strong El Niño events in the latter part of the 20th Century: the 1986/87/88 and 1997/98 El Niños. (The 1982/83 El Niño was also a strong event, but the eruption of El Chichon in 1982 counteracted its impacts.) We'll illustrate this disproportional response of the North Atlantic sea surface temperatures to El Niño and La Niña events in the upcoming chapter about the El Niño-Southern Oscillation.
- Long-term changes in wind patterns on the surface of the North Atlantic can also cause variations in the rates of Atlantic Meridional Overturning Circulation (thermohaline circulation), which, in turn, would also impact the Atlantic Multidecadal Oscillation. Changes in surface wind patterns are also reflected in the sea level pressures of the North Atlantic. Both were discussed in the 2014 paper Wind-forced interannual variability of the Atlantic Meridional Overturning Circulation at 26.5°N by Zhao and Johns. They mention the North Atlantic Oscillation, which is a sea level pressure-based index. It is not to be confused with the Atlantic Multidecadal Oscillation, which is a sea surface temperature-based index. McCarthy et al. (2015) Ocean impact on decadal Atlantic climate variability revealed by sea-level observations confirmed that the Atlantic Multidecadal Oscillation is linked with the North Atlantic Oscillation. We'll discuss the North Atlantic Oscillation later in this section.

Later in this chapter we'll show that the climate forcings used to drive the climate models cannot simulate the additional variability in the sea surface temperatures of the

North Atlantic, which indicates the Atlantic Multidecadal Oscillation is a naturally occurring, not man-made, phenomenon.

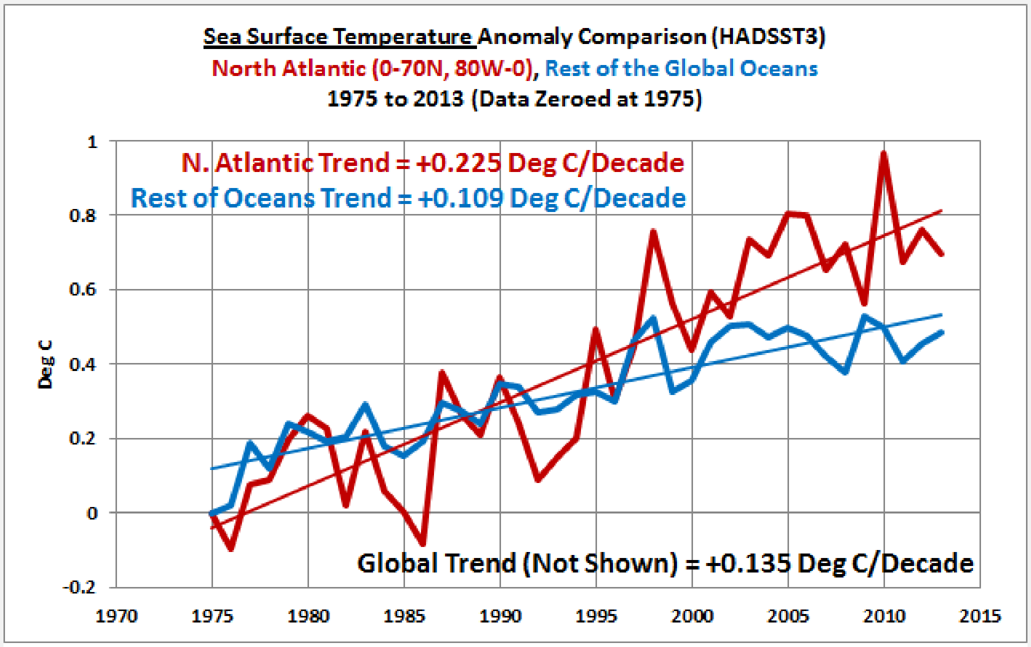
HOW DEEP INTO THE NORTH ATLANTIC DOES THE ATLANTIC MULTIDECADAL OSCILLATION EXTEND?

We've already shown that 1975 is the approximate breakpoint year between the latest cooling and warming periods of the Atlantic Multidecadal Oscillation so we'll start the data in 1975 for this part of the presentation. We'll start with sea surface temperature data and then look at vertically average temperature data for the depths of 0-100 meters (0-330 feet), 0-700 meters (0-2300 feet) and 0-2000 meters (0-6550 feet).

Why aren't we looking at data farther back in time? Basically, it's the lack of reliable data. (1) To gain a full opposing cycle, we'd want to extend the data back to the mid-1940s, but subsurface temperature data are only available back to the mid-1950s. (2) Globally complete subsurface ocean temperature data only exist back to the early 2000s, we'll expand on this in a few moments, so that has to be consider when looking the data before then. We're really only getting a rough idea with this exercise.

To simplify this discussion, we'll be comparing the warming rates of annual North Atlantic data and the global data without the North Atlantic. That is, we'll be comparing the North Atlantic data to the rest of the global oceans, with the intent of showing how much faster the North Atlantic had warmed than the rest of the global oceans during the recent warming period. To remove the North Atlantic data from the global data, we'll assume the North Atlantic represents 11.5% of the surface area of the global oceans. See the NOAA National Geophysical Data Center webpage here. I've also zeroed the data in 1975. Last, I've listed the trends for the global data even though they are not illustrated, so that we can see how much the additional variability of the North Atlantic has added to the warming rates for the global oceans since 1975.

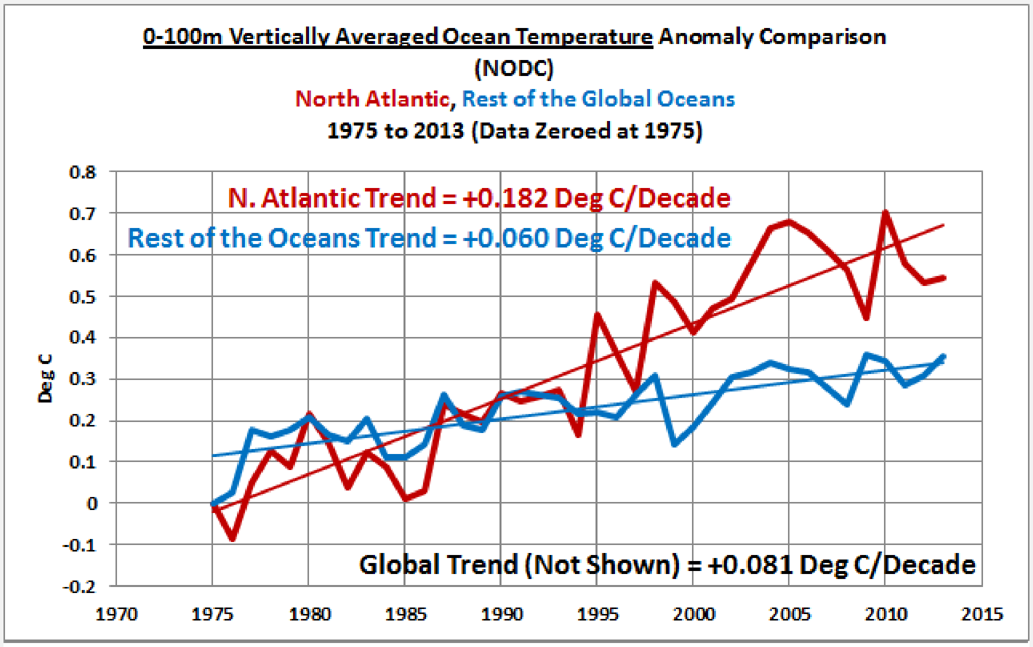
The sea surface temperature data in Figure 3.3-19 is based on the HADSST3 data from the UKMO. It is available through the KNMI Climate Explorer. I've used the standard coordinates of the 0-70N, 80W-0 for the North Atlantic. As we can see, the sea surface temperatures of the North Atlantic warmed at a rate that was more than 2 times faster than the rest of the global oceans. That additional warming was a response to the naturally occurring Atlantic Multidecadal Oscillation. By comparing the trend of the global oceans to the global oceans without the North Atlantic, we can see that the Atlantic Multidecadal Oscillation added about 24% to the warming rate of the global oceans since 1975, based on the UKMO HADSST3 data.



Note: Data For The "Rest of the Global Oceans" Are Based On The North Atlantic Data Representing 11.5% Of The Global Data.

Figure 3.3-19

# # #



Note: Data For The "Rest of the Global Oceans" Are Based On The North Atlantic Data Representing 11.5% Of The Global Data.

Figure 3.3-20

Let's look at the top 100 meters (330 feet) of the oceans, Figure 3.3-20. For this, we're using the vertically average temperature data from the National Oceanographic Data

Center (NODC). The NODC provides the depth averaged temperature data for three depth ranges. This is the uppermost level. Again, for this discussion, we're assuming the North Atlantic represents 11.5% of the surface of the global oceans.

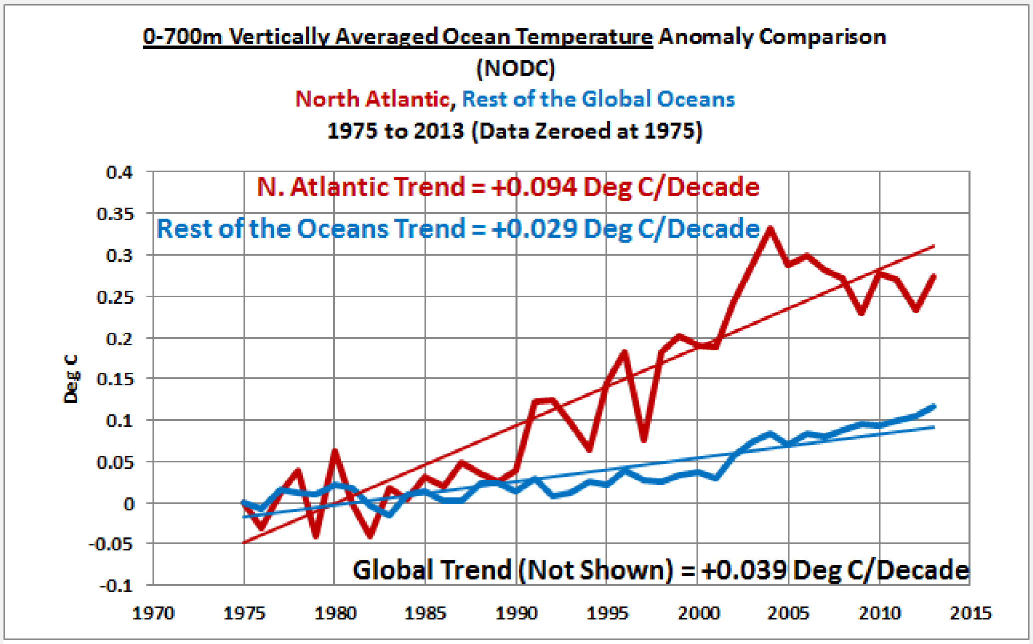
For the depths of 0-100 meters (330 feet), the North Atlantic warmed at a rate that was about 3 times faster than the warming rate for the rest of the global oceans since 1975. And, again, by comparing the warming rates of the global oceans and the global oceans without the North Atlantic we can see that the North Atlantic added about 35% to the warming of the global oceans, to depths of 0-100 meters (330 feet) during that time.

IMPORTANT NOTE: Before the ARGO floats were deployed in the early 2000s, subsurface ocean temperatures were sampled very poorly…very poorly. The following is a quick overview. Before the early 2000s, subsurface ocean temperatures:

- were sampled better in the North Atlantic than in the North Pacific (but that's relative because even the North Atlantic was sampled poorly, so the sampling in the North Pacific was simply worse)
- were sampled better in the Northern Hemisphere than the Southern Hemisphere (but there were few to no measurements in the Southern Hemisphere, so the fact that there are more measurements in the Northern Hemisphere isn't necessarily a good thing) and
- were sampled better nearer the surface than at deeper levels (and unfortunately we're just as interested in the variations in the deeper levels as we are nearer the surface).

We'll discuss and illustrate this in much more detail later in Part 2 of this book. Bottom line: we have to look at any subsurface ocean temperature-based data prior to the early 2000s with a very skeptical eye. Globally complete source data to the depths of the oceans simply do not exist prior to ARGO.

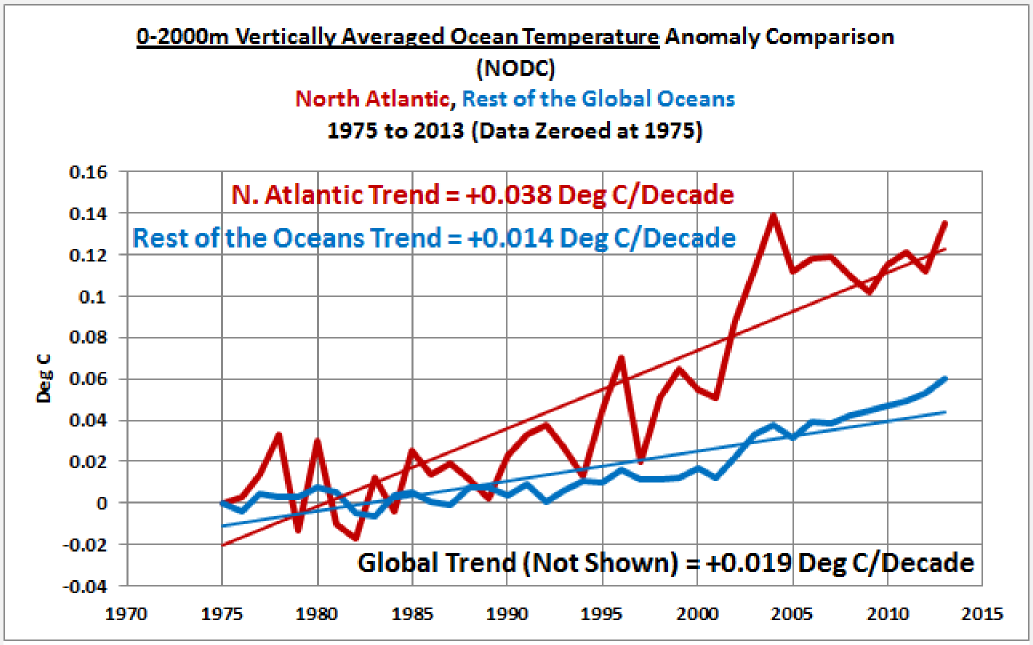
With that in mind, let's take a look at the NODC's vertically averaged temperature data for the top 700 meters (2300 feet) of the oceans. Refer to Figure 3.3-21. The same basic relationship exists. That is, the North Atlantic to depths of 0-700 meters (0-2300 feet) warmed at a rate that was much faster (almost 3.25 times faster) than the rest of the global oceans from 1975 to 2013. And that means the North Atlantic contributed about 34% to the warming of the global oceans to 700 meters (2300 feet) during that period, even though its surface only covers 11.5% of the global oceans.



Note: Data For The "Rest of the Global Oceans" Are Based On The North Atlantic Data Representing 11.5% Of The Global Data.

Figure 3.3-21

# # #



Note: Data For The "Rest of the Global Oceans" Are Based On The North Atlantic Data Representing 11.5% Of The Global Data.

Figure 3.3-22

The deepest dataset from the NODC reaches from the surface to 2000 meters (about 6600 feet, or about 1.25 miles). See Figure 3.3-22. The same basic relationship exists to those depths as well. The North Atlantic warmed at a much faster rate than the rest of the oceans, about 2.7 times faster since 1975. And even though the North Atlantic represents only 11.5% of the surface of the global oceans, it contributed more than one-third of the warming of the global oceans to depths of 2000 meters (6600 feet) for period of 1975 to 2013.

Why was that important? From the surface to depths of 1.25 miles, a major portion (from 25% to 35%) of the warming of the global oceans occurred without being forced to do so by man-made greenhouse gases, and that was based solely on our simple analysis of data. Later in this chapter we'll present a paper that discussed how all of the warming of the North Atlantic to depths of 700 meters occurred naturally…not just some of the warming, all of the warming.

ANOTHER IMPORTANT NOTE: Notice the global trend in Figure 3.3-22. It presents the warming rate of about +0.02 deg C/decade (about +0.036 deg F/decade) for the global oceans to depths of 2000 meters (6600 feet), for the period of 1975 to 2013. That's 2 one-hundredths of a degree Celsius per decade or 36 one-thousandths of a degree Fahrenheit per decade. It's hard to grasp warming at a rate that small. Most people have trouble trying to understand what all of the hubbub is about for a global surface temperature warming rate of +0.17 deg C/decade (about +0.3 deg F/decade). Imagine trying to tell them that all of the alarm is about a warming rate of +0.02 deg C/decade (about +0.036 deg F/decade) for the global oceans to depths of 2000 meters (6600 feet), for the period of 1975 to 2013—a period over most of which the ocean temperature sampling is horrendous. [End note.]

THE NORTH ATLANTIC IS NO LONGER CONTRIBUTING TO GLOBAL WARMING

As you were viewing the last 4 graphs, you may have noticed that the warming of the North Atlantic appeared to have slowed in the past decade. It reality, the North Atlantic sea surface temperatures and its vertically averaged temperatures at the depths of 0-100 meters (0-330 feet), 0-700 meters (0-2300 feet) and 0-2000 meters (0-6550 feet) stopped warming in 2003. That is, based on the linear trends, North Atlantic temperature trends are either flat or slightly negative (indicating a very slight cooling) for the period of 2003 to 2013. See Figure 3.3-23.

I've left the data zeroed at 1975 in Figure 3.3-23 so that we can see the differences in the variations and the cooling rates for the different datasets.

The fact that the North Atlantic has not warmed is important because it had been a major contributor to the warming of surface temperatures and of the global oceans to depths of 2000 meters (6600 feet), and now the North Atlantic is no longer contributing to that warming.

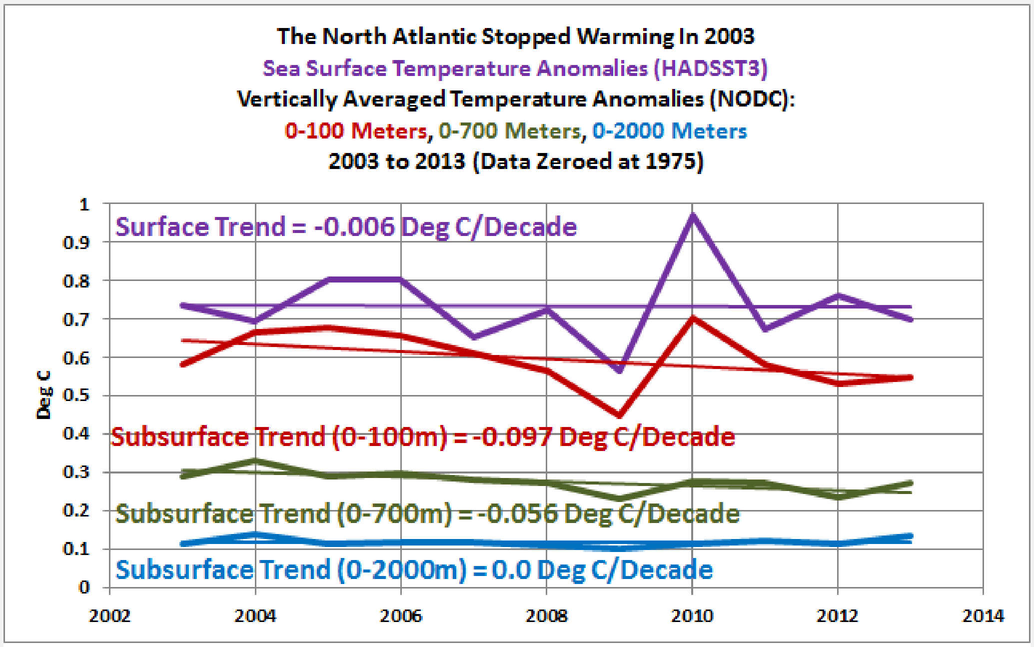


Figure 3.3-23

You'll note that I did not bother to update Figure 3.3-23 with 2014 data. From 2013 to 2014, the surface temperature of the North Atlantic and subsurface temperatures there for the depths of 0-100 meters and 0-700 meters all cooled slightly. And the subsurface temperature data for the depths of 0-2000 meters made a slight uptick of 0.01 deg C.

CORRELATION OF NORTH ATLANTIC SEA SURFACE TEMPERATURE DATA WITH NORTHERN HEMISPHERE LAND-PLUS-SEA SURFACE TEMPERATURE DATA

Correlation analysis is one of the tools that climate scientists use to illustrate where the variations in one variable (surface temperatures, for example) in one area (let's call in the primary area) may interact with other regions of the globe (and we'll call them secondary areas) and cause a variable like surface temperatures in the secondary regions to warm or cool. Or if they were studying precipitation, they could use correlation analysis to determine where a change in the sea surface temperatures in the primary research area might be having an impact on precipitation in secondary areas.

But there is an often-seen statement that's quite true, that correlation does not necessarily mean causation. So the climate scientists then have to determine the processes through which the change in the variable in the primary area could cause changes in the variable in the secondary areas. They have to determine those processes because there are numerous other factors that could cause the two variables to vary at the same time by similar magnitudes.

Software is available through the KNMI Climate Explorer that can create color-scaled maps of where one dataset correlates with another, at differing levels of correlation. While it doesn't tell you that there is an actual relationship between the two variables, it does tell you that there could be a relationship. It can also give you an idea of whether a primary variable in one area (the sea surface temperatures North Atlantic, for example) might have a greater impact on land surface temperatures in the Northern Hemisphere (the secondary variable) than another primary variable (such as the sea surface temperatures of the North Pacific). We'll compare those two in the next chapter. But let's take a look at where surface temperatures (in general) of the Northern Hemisphere correlate with the sea surface temperatures of the North Atlantic, and in doing so we'll get an idea of the extent of the possible impact of the North Atlantic sea surface temperatures on the surface temperatures of the rest of the Northern Hemisphere.

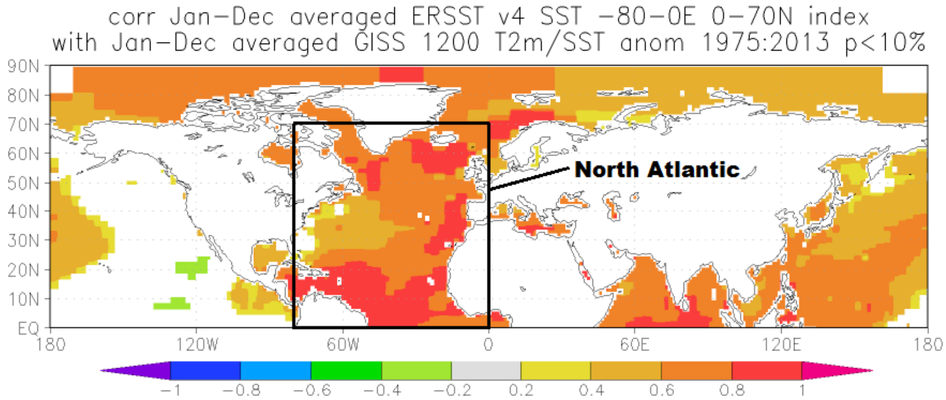
Keep in mind that correlation maps such as these key off the larger variations in the data.

Figure 3.3-24 contains 3 correlation maps, which I created at the KNMI Climate Explorer. I've presented the GISS Land-Ocean Temperature Index data because it's been infilled so that it is spatially complete. All three maps illustrate the correlation of Northern Hemisphere surface temperature anomalies on an annual basis with North Atlantic sea surface temperature anomalies. I've highlighted the North Atlantic (0-70N, 80W-0) in the top map (Cell a) of sea surface temperature anomalies. You'll note, logically, the correlation of Northern Hemisphere sea surface data with the North Atlantic sea surface temperature anomalies is best in the North Atlantic. You'll also note that the correlation there is not perfect, which makes sense because the sea surface temperature anomalies do not vary in unison across the North Atlantic. Moderate correlations (0.6 to 0.8) and higher correlations (0.8 to 1.0) also exist in the North Indian Ocean and in the western tropical North Pacific. The center map (cell b) illustrates the annual correlation of land surface air temperature anomalies for the Northern Hemisphere with North Atlantic sea surface temperature anomalies. Parts of Greenland, South America, tropical Africa, and Southeast Asia correlate best with the sea surface temperature anomalies of the North Atlantic. And in the bottom map (cell c) the map includes the combined land-plus-sea surface temperature data. What stands out in it is that large parts of the Eastern North Pacific show no correlation with the North Atlantic sea surface temperature anomalies, while most of the rest of the Northern Hemisphere show as least some correlation. The other region where there appears to be little relationship with the North Atlantic is north-central Siberia.

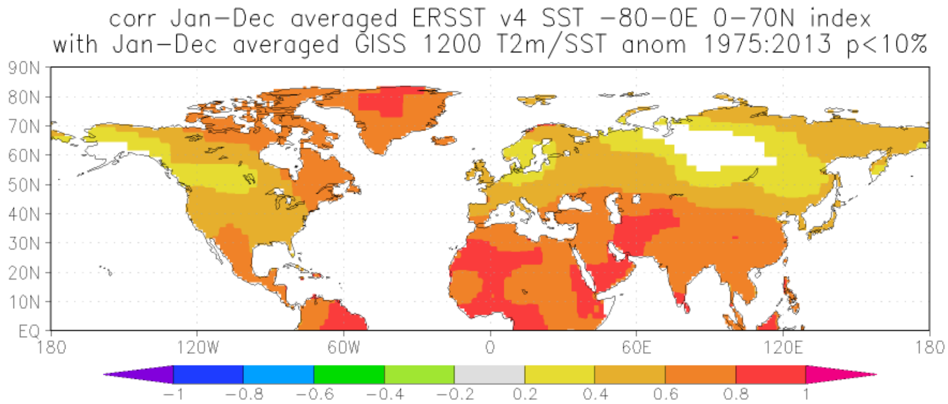
Correlation of Annual North Atlantic (0-70N, 80W-0) Sea Surface Temperature Anomalies With Northern Hemisphere Surface Temperature Anomalies

(NOAA ERSST.v3b And GISS Land-Ocean Temperature Index for 1975 to 2013)

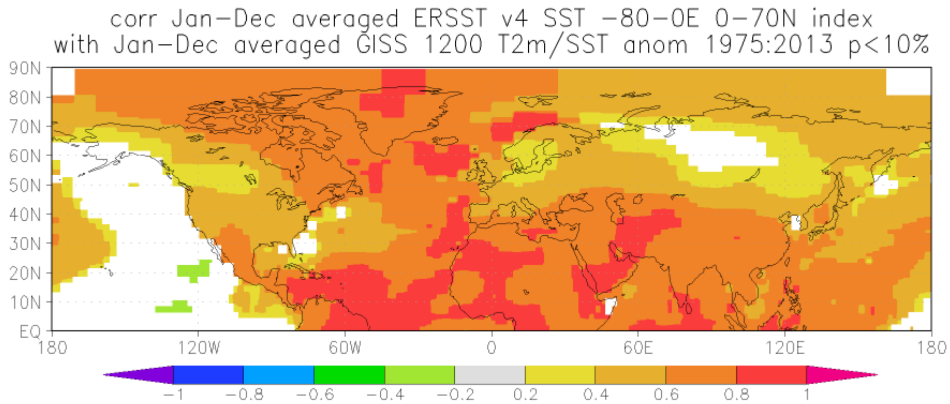
(a) **Sea Surface Temperature Anomalies**



(b) **Land Surface Air Temperature Anomalies**



(c) **Land-Plus-Sea Surface Temperature Anomalies**



Maps Created at KNMI Climate Explorer

Figure 3.3-24

So the naturally occurring variations in the sea surface temperatures of the North Atlantic can have far-reaching impacts throughout the Northern Hemisphere.

The impacts of the Atlantic Multidecadal Oscillation on precipitation, surface temperatures, Arctic sea ice, hurricane intensity, etc., are well studied.

CAN CLIMATE MODELS SIMULATE THE ATLANTIC MULTIDECADAL OSCILLATION?

If we're discussing climate models specifically designed and programed to study the Atlantic Multidecadal Oscillation, climate scientists are able to produce models that simulate multidecadal variations in the sea surface temperature anomalies of the North Atlantic.

If we're discussing climate models used by the IPCC for projections of future climate and for hindcasts of past climate, the one-word answer is no. We only have to return once again to the 2007 article Predictions of Climate by Dr. Kevin Trenberth at the Nature.com's blog ClimateFeedback (my boldface and underline):

> ***None of the models used by IPCC are initialized to the observed state and none of the climate states in the models correspond even remotely to the current observed climate****. In particular, the state of the oceans, sea ice, and soil moisture has no relationship to the observed state at any recent time in any of the IPCC models. There is neither an El Niño sequence nor any Pacific Decadal Oscillation that replicates the recent past; yet these are critical modes of variability that affect Pacific rim countries and beyond.* ***The Atlantic Multidecadal Oscillation, that may depend on the thermohaline circulation and thus ocean currents in the Atlantic, is not set up to match today's state, but it is a critical component of the Atlantic hurricanes and it undoubtedly affects forecasts for the next decade from Brazil to Europe****. Moreover, the starting climate state in several of the models may depart significantly from the real climate owing to model errors. I postulate that regional climate change is impossible to deal with properly unless the models are initialized.*

Additionally, in the 2013 paper The Atlantic Multidecadal Oscillation in Twentieth Century Climate Simulations: Uneven Progress from CMIP3 to CMIP5, Ruiz-Barradas, et al. (2013) start with the understanding that the models simply don't simulate the properties of the Atlantic Multidecadal Oscillation.

A few more comments on this topic: Climate modelers choose to ignore the multidecadal variations in the temperatures of the North Atlantic, and they have tuned their models to the latest upswing in the Atlantic Multidecadal Oscillation. This, of course, creates a problem for the modelers, because it overlooks a few things:

1. as we've shown, the Atlantic Multidecadal Oscillation contributed to global warming from the mid-1970s to about 2005,
2. the sea surface temperatures (and subsurface temperatures) of the North Atlantic show no warming for the past decade, and
3. the North Atlantic surface temperatures will likely cool sometime over the next few decades, before they swing upwards once again…with the upswing possibly occurring in the 2030s.

THE ATLANTIC MULTIDECADAL OSCILLATION IS NOT DRIVEN BY THE FORCINGS USED TO DRIVE CLIMATE MODELS

I'm going to borrow a graph, Figure 3.3-25, from the October 2013 blog post Questions the Media Should Be Asking the IPCC – The Hiatus in Warming. There it was presented as Figure 3. The fact that the data and models end 2 years ago have no impact on this presentation.

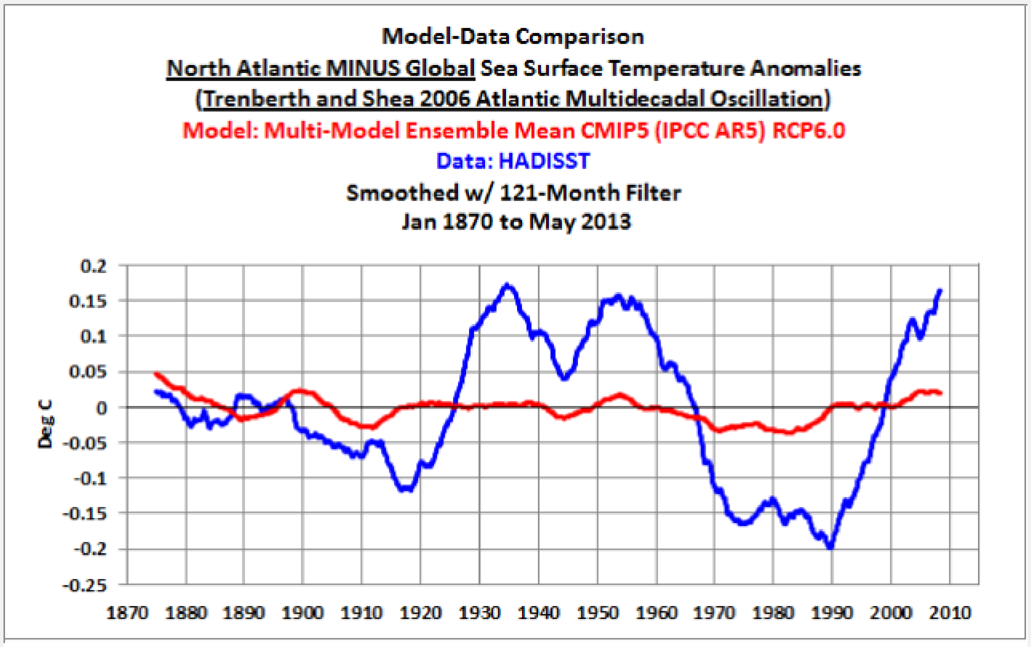


Figure 3.3-25

For this model-data comparison we're presenting the Atlantic Multidecadal Oscillation using the method recommended by Trenberth and Shea (2006). That is, we're subtracting global sea surface temperature anomalies (60S-60N, excludes the polar oceans) from sea surface temperature anomalies of the North Atlantic (0-60N, 80W-0). Trenberth and Shea used HADISST data and so have I. In the time-series graph in Figure 3.3-25, I've also smoothed the AMO data and model outputs with 121-month running-average filters. As shown by the blue curve, the North Atlantic has a mode of natural variability that causes its sea surface temperatures to warm and cool at rates that are much greater than the variations in the surface temperatures of the global oceans.

When we subtract the modeled global sea surface temperature anomalies from the modeled sea surface temperature anomalies of the North Atlantic (shown as the red curve in Figure 3.3-25), we can see that the model mean of the CMIP5 models does not simulate the observed multidecadal variations in the North Atlantic. That is, there is comparatively very little difference between the modeled variations in global and North Atlantic sea surface temperature anomalies. That, of course indicates, in the average of the models, the sea surface temperatures of the North Atlantic basically vary in synch with the rest of the global oceans over multidecadal timeframes.

Keep in mind that the model mean represents the forced component of the models, according to Dr. Gavin Schmidt, Director of GISS. As discussed in Chapter 2.11, Dr. Schmidt wrote in a comment on the thread of the RealClimate blog post Decadal Predictions (my boldface):

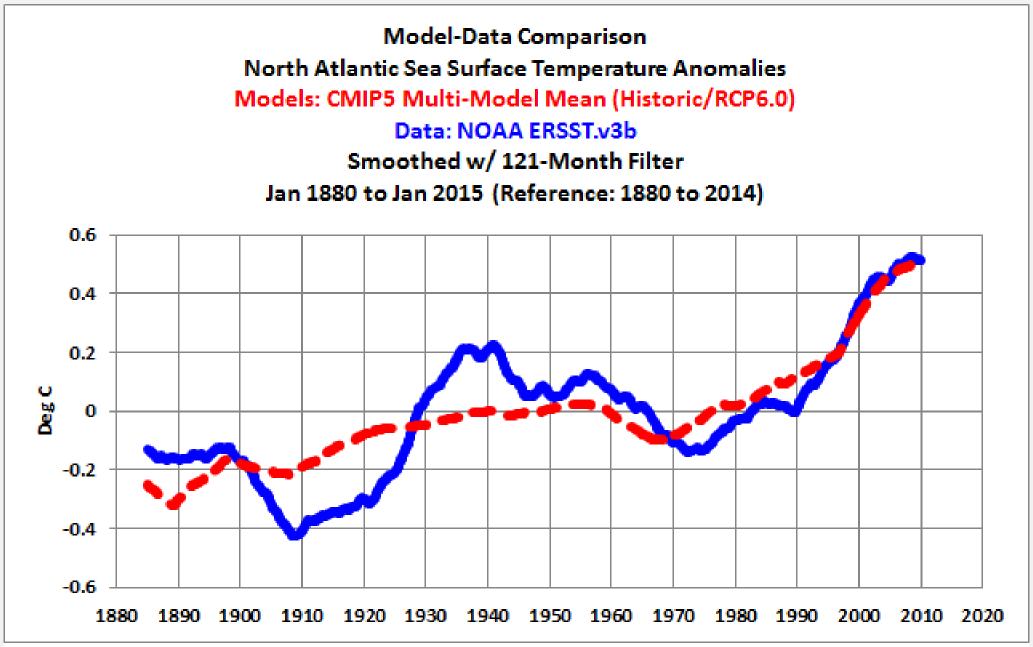
> *Any single realisation can be thought of as being made up of two components – a forced signal and a random realisation of the internal variability ('noise'). By definition the random component will uncorrelated across different realisations and* ***when you average together many examples you get the forced component (i.e. the ensemble mean)****.*

The comparison indicates that the Atlantic Multidecadal Oscillation is NOT a response to man-made greenhouse gases (or aerosols) used by the climate modelers to force the warming (or cooling) of sea surface temperatures of the North Atlantic.

MISDIRECTION FROM THE CLIMATE SCIENCE COMMUNITY

This very basic understanding (that the Atlantic Multidecadal Oscillation is NOT a response to man-made greenhouse gases (or aerosols) used by the climate modelers to force the warming (or cooling) of sea surface temperatures of the North Atlantic) counters a recent (foolish) attempt to redefine the Atlantic Multidecadal Oscillation as the difference between the observed and modeled sea surface temperature anomalies of the North Atlantic. See Steinman et al. (2015) Atlantic and Pacific multidecadal oscillations and Northern Hemisphere temperatures. That is, Steinman et al. (2015) subtracted the modeled sea surface temperature anomalies of the North Atlantic from the data. This assumes that all of the warming since the mid-1970s is caused by the forcings used to drive the climate models. That's a blatantly incorrect assumption when we have shown that the Atlantic Multidecadal Oscillation is NOT a forced component of the models.

What Steinman et al. have done is similar to subtracting an exponential curve from a sine wave…where the upswing in the exponential curve aligns with the last minimum to maximum of the sine wave…without first establishing a relationship between the two totally different curves. Let's look at the modeled and observed sea surface temperature anomalies of the North Atlantic (not the AMO) to clarify that statement. See Figure 3.3-26.



Figue 3.3-26

As illustrated, the data indicate the surfaces of the North Atlantic are capable of warming and cooling at rates that are very different over multidecadal periods than the forced component of the climate models, which is represented by the multi-model mean. In fact, the surfaces of the North Atlantic cooled from the 1880s to about 1910, but the cooling wasn't captured by the models. The surfaces there warmed from about 1910 to about 1940 at a rate that was much higher than hindcast by the models. They then cooled from about 1940 to the mid-1970s at a rate that was very different than the models. Not too surprisingly, as a result of their programming, the models then align much better during the period after the mid-1970s.

Another case of misdirection comes from the 2012 Booth et al. paper [Aerosols implicated as a prime driver of twentieth-century North Atlantic climate variability](). The title gives you an idea of the content of their paper. The abstract reads (my boldface and underline):

> *Systematic climate shifts have been linked to multidecadal variability in observed sea surface temperatures in the North Atlantic Ocean*[1]*. These links are extensive, influencing a range of climate processes such as hurricane activity*[2] *and African*

Sahel[3, 4, 5] and Amazonian[5] droughts. The variability is distinct from historical global-mean temperature changes and is commonly attributed to natural ocean oscillations[6, 7, 8, 9, 10]. A number of studies have provided evidence that aerosols can influence long-term changes in sea surface temperatures[11, 12], but climate models have so far failed to reproduce these interactions[6, 9] and the role of aerosols in decadal variability remains unclear. ***Here we use a state-of-the-art Earth system climate model to show that aerosol emissions and periods of volcanic activity explain 76 per cent of the simulated multidecadal variance in detrended 1860–2005 North Atlantic sea surface temperatures.*** *After 1950, simulated variability is within observational estimates;* ***our estimates for 1910–1940 capture twice the warming of previous generation models but do not explain the entire observed trend.*** *Other processes, such as ocean circulation, may also have contributed to variability in the early twentieth century. Mechanistically, we find that inclusion of aerosol–cloud microphysical effects, which were included in few previous multimodel ensembles, dominates the magnitude (80 per cent) and the spatial pattern of the total surface aerosol forcing in the North Atlantic. Our findings suggest that anthropogenic aerosol emissions influenced a range of societally important historical climate events such as peaks in hurricane activity and Sahel drought. Decadal-scale model predictions of regional Atlantic climate will probably be improved by incorporating aerosol–cloud microphysical interactions and estimates of future concentrations of aerosols, emissions of which are directly addressable by policy actions.*

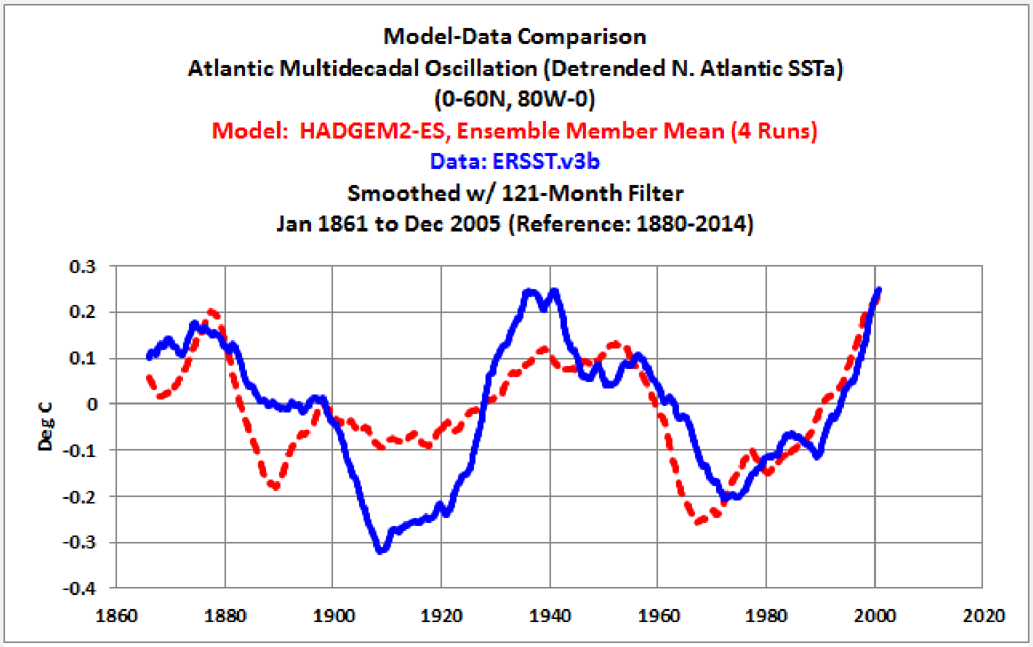


Figure 3.3-27

The model used by Booth et al. (2012) is the HADGEM2-ES, which was documented in Jones et al. (2011) The HadGEM2-ES implementation of CMIP5 centennial simulations. For my presentation in Figure 3.3-27, I've used slightly different base years for anomalies, but that makes no difference since we're detrending the data and models. I've also used slightly different coordinates for the North Atlantic. The coordinates I've chose agree with those used by Trenberth and Shea for their method of determining the AMO (which we'll look at in a few moments). The coordinates should have little to no impact on the model-data presentation. I've also used the 4 HADGEM2-ES ensemble members (historic forcings through 2005) that are linked to the RCP8.5-based projections at the KNMI Climate Explorer…just in case you're trying to replicate my findings. Booth et al. used ERSST.v3b data from NOAA for their observations, so I've used the same. Also, Booth et al. ended their analysis in 2005 to capture the hindcasts only, so I've ended the models and data then too.

The Booth et al. claim "…our estimates for 1910–1940 capture twice the warming of previous generation models but do not explain the entire observed trend" is quite the understatement. Based on the smoothed model outputs and data shown in Figure 3.3-27, the data show roughly 3 times the warming shown by the model mean from around 1910 to 1940. And the reason the models fail to show the warming at that time is because they fail to simulate the cooling that took place from the 1880s to 1910. The HADGEM2-ES models are also a decade or so too soon for the change from cooling to warming (roughly 1965) for the models versus 1975 for the data. Other than those obvious differences, the models appear to capture the basic variations from 1950 to 2005 as Booth et al. have claimed. Then again, that's only 56 years out of the 145 years presented by them. Somehow they consider that a success.

On the other hand, if we use the Trenberth and Shea method to determine the Atlantic Multidecadal Oscillation (North Atlantic minus global sea surface temperature anomalies), the model mean of the HADGEM2-ES models show few similarities to the ERSST.v3b-based observations. This indicates that the aerosols over the North Atlantic were not responsible for the additional multidecadal variations in surface temperatures of the North Atlantic compared to the global oceans.

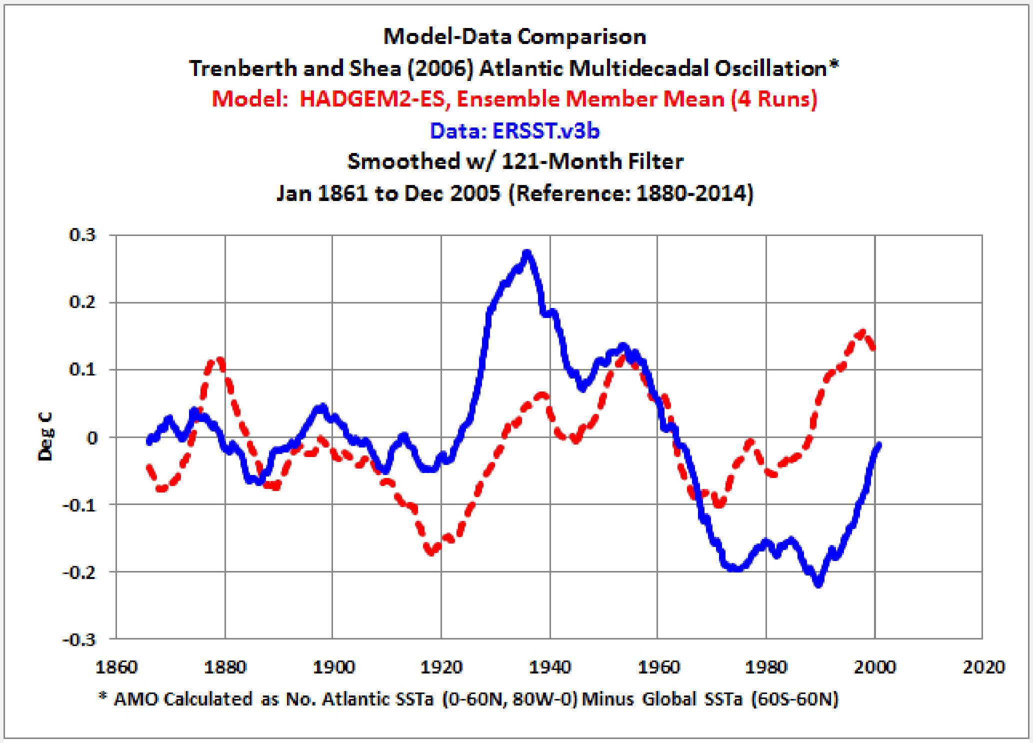


Figure 3.3-28

SUMMARY

While the Atlantic Multidecadal Oscillation is normally presented as detrended long-term sea surface temperature data for the North Atlantic, it is best portrayed as the difference between the sea surface temperatures of the North Atlantic versus those of the rest of the global oceans. That way the Atlantic Multidecadal Oscillation is presented as the additional variations in the North Atlantic.

The Atlantic Multidecadal Oscillation is a naturally occurring variation, inasmuch as the forced components of all the climate models used by the IPCC cannot simulate the additional multidecadal variations in the surface temperatures of the North Atlantic. See Figure 3.3-25.

As NOAA notes, the Atlantic Multidecadal Oscillation can contribute naturally to global warming and can suppress it as well.

Importantly, the additional, naturally caused variations in North Atlantic contributed very noticeably to the warming in both the Northern Hemisphere and globally from the mi-1970 to about 2005. Yet, the IPCC tells us that all of the global warming during that period was caused by man-made greenhouse gases.

Though not discussed in this chapter, the Atlantic Multidecadal Oscillation was first identified in 1994. (See Schlesinger and Ramankutty (1994) An oscillation in the global climate system of period 65-70 years.) Two decades later, climate models used for attributing global warming to mankind and for future prognostications of global warming do not include the Atlantic Multidecadal Oscillation. And the modelers continue to assume the additional warming associated with the Atlantic Multidecadal Oscillation was caused by man-made greenhouse gases even though data contradict that assumption.

3.4 – Ocean Mode: North Pacific Multidecadal Variability

INITIAL NOTES: This chapter is not a discussion of the Pacific Decadal Oscillation (PDO) by its classic definition. The Pacific Decadal Oscillation is covered in the next chapter.

This chapter was originally prepared in April 2014. I've updated most of the illustrations due to the impacts of The Blob in 2014 and 2015 and the strong El Niño in 2015.

# # #

The sea surface temperatures of the North Pacific also have variations similar to the variations in the North Atlantic called the Atlantic Multidecadal Oscillation. However, the naturally occurring multidecadal variations in the sea surface temperatures of the North Pacific are smaller than those of the North Atlantic, and the variations in the North Pacific can run in and out of phase with those of the North Atlantic.

For the most part, the multidecadal variations in the sea surface temperatures of the North Pacific have been ignored by the climate science community. There are numerous papers about the Pacific Decadal Oscillation (PDO) but the Pacific Decadal Oscillation does not represent the sea surface temperatures of the North Pacific, where it is derived. (More on the Pacific Decadal Oscillation in the next chapter.) Some persons might think climate scientists ignore the additional variability in the sea surface temperatures of the North Pacific, because it's yet another mode of natural variability that climate models cannot simulate. There may be another reason why it seems to be overlooked, and we'll illustrate it in a few moments.

DETRENDED NORTH PACIFIC SEA SURFACE TEMPERATURE ANOMALIES

The simplest way to present the multidecadal variations in the North Pacific sea surface temperature anomalies is to detrend them…just like NOAA does for their Atlantic Multidecadal Oscillation Index. Figure 3.4-1 presents the detrended North Pacific data (based on the UKMO's HADSST3 reconstruction) for the period of January 1870 through August 2015. I've included a map in Figure 3.4-2 to illustrate the coordinates used for the North Pacific data (0-65N, 100E-90W). They capture small portions of the Gulf of Mexico and Hudson Bay, but those extras have little impact on this discussion.

The impacts of the El Niño in 2015 and the unusual (natural) warming event in the eastern extratropical Pacific in 2013 and 2014 stand out as a spike at the end of the detrended data. Note how the monthly data become more volatile before 1900. That's the result of fewer and fewer grids containing data…and the sampling occurring less often. With fewer grids and less sampling, there is less data included in the monthly average, so the monthly data have greater “weather-related” variations.

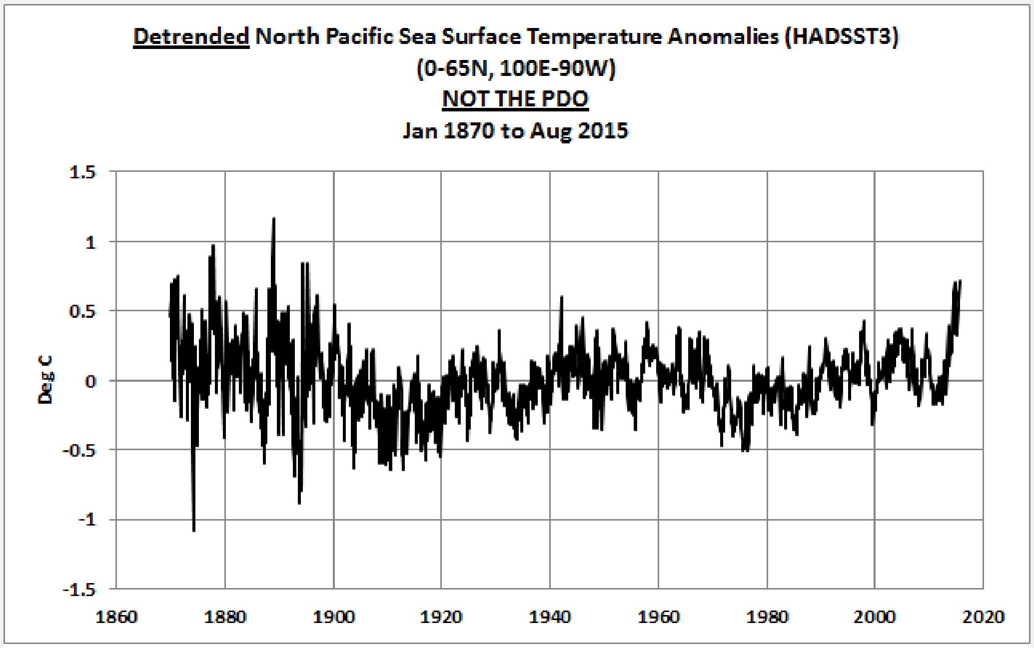


Figure 3.4-1

# # #

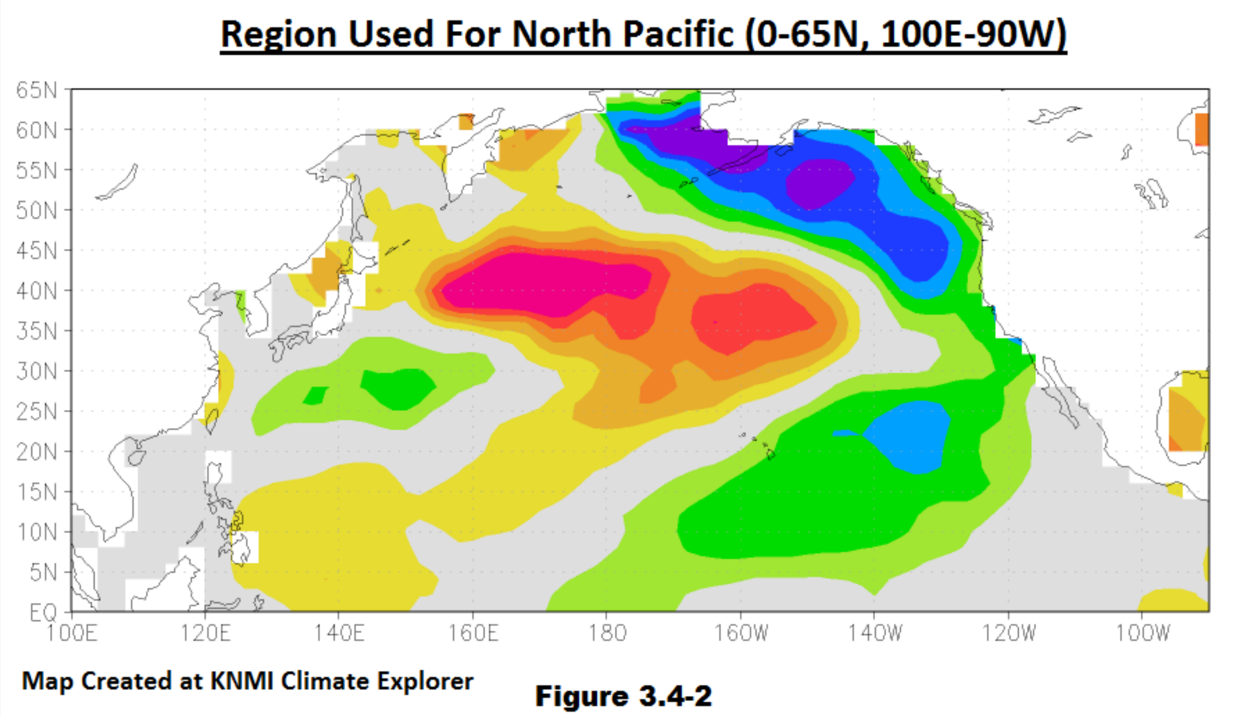


Figure 3.4-2

# # #

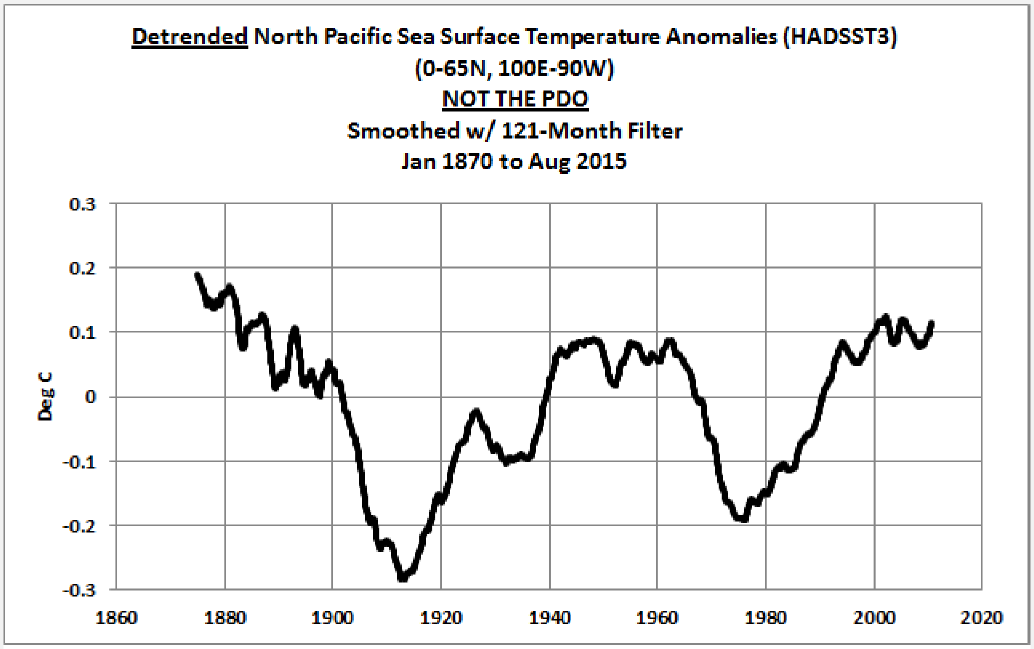


Figure 3.4-3

In Figure 3.4-3, the detrended North Pacific sea surface temperature anomalies have also been smoothed with a 121-month filter to help show the underlying variability. The sea surface temperatures there clearly vary over multidecadal timeframes. The minimums of the cycles in the detrended data, in the 1910s and the mid-1970s, stand out, but the mid-20th Century maximum is not as clear. They plateau from the early 1940s to the early 1960s, with some minor variations in between.

THE SEA SURFACE TEMPERATURES OF THE NORTH PACIFIC DO NOT DEVIATE TOO FAR FROM THE GLOBAL DATA

Earlier I noted that the multidecadal variations in the sea surface temperatures of the North Pacific were pretty much ignored by the climate science community. The likely reason is that the sea surface temperature anomalies of the North Pacific do not deviate too far from the global data…at least the additional variations are not as great as they are in the North Atlantic. We can see this in Figure 3.4-4, which compares long-term global, North Pacific and North Atlantic sea surface temperature anomalies (not detrended), with the data smoothed with 121-month filters.

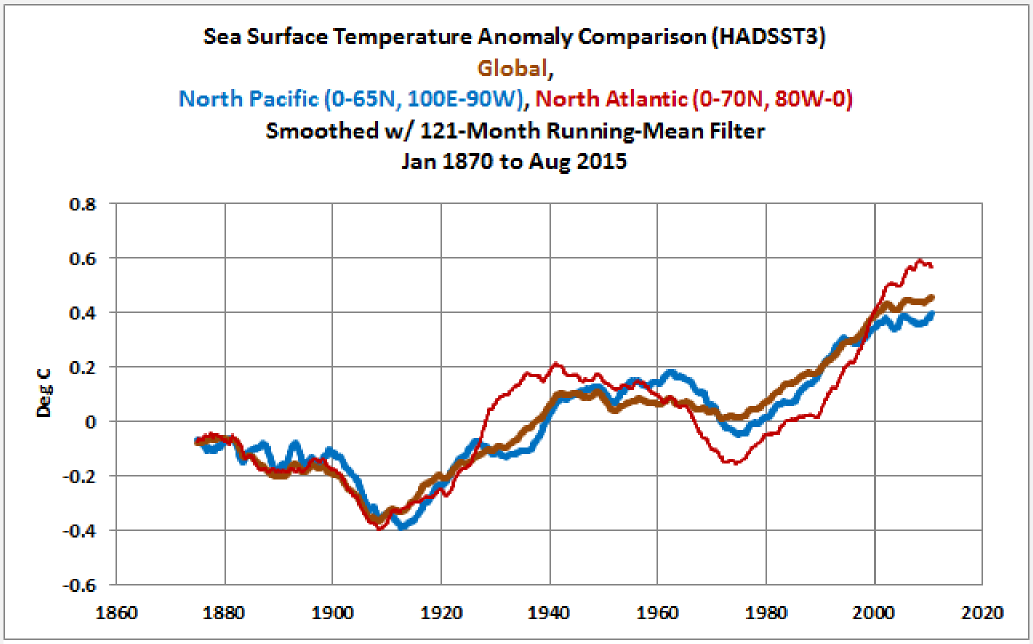


Figure 3.4-4

The North Pacific and North Atlantic sea surface temperature data are detrended in Figure 3.4-5. The amplitudes of the multidecadal variations in the sea surface temperature of the North Pacific are a good bit less than those of the North Atlantic, except during the period before about 1910 when the two drop by about the same amount. And, as noted earlier, the variations of the two Northern Hemisphere ocean basins can run in and out of phase with one another.

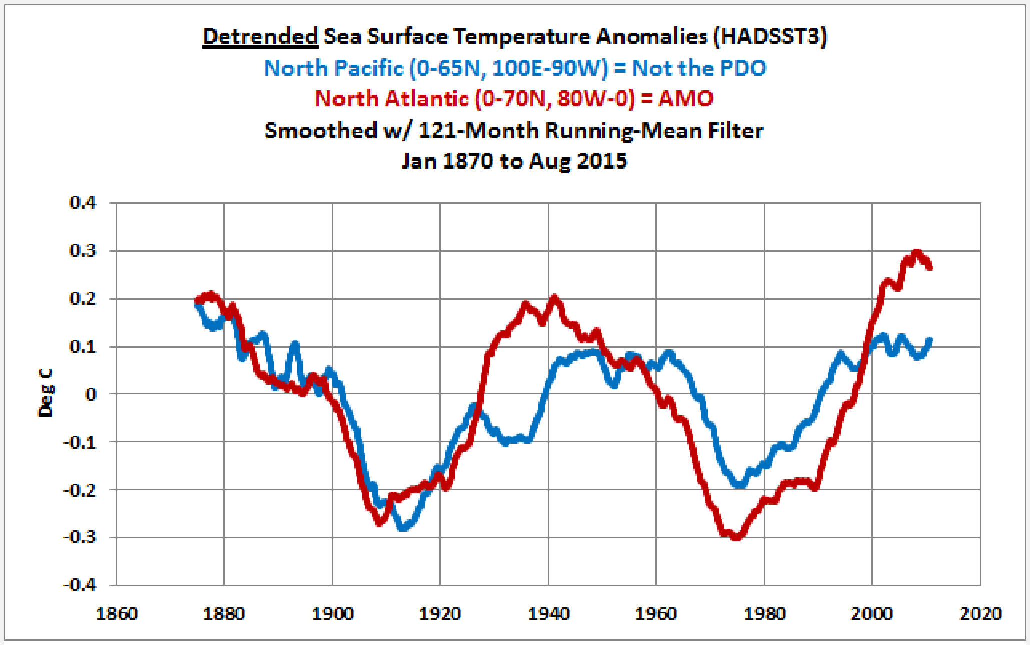


Figure 3.4-5

ANOTHER WAY OF ILLUSTRATING THE ADDITIONAL VARIABILITY OF THE SEA SURFACE TEMPERATURES IN THE NORTH PACIFIC

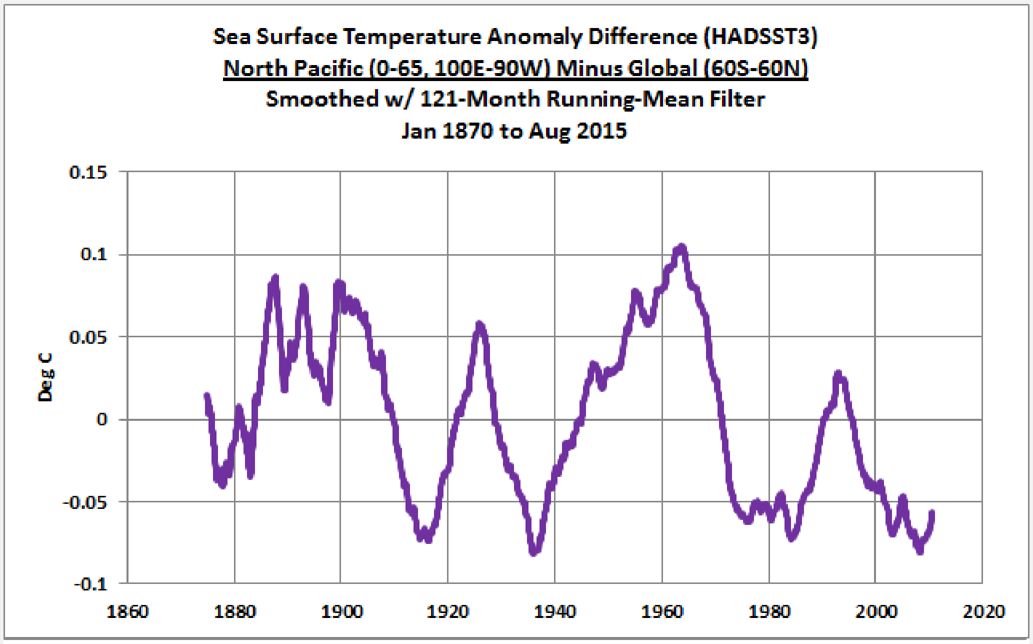


Figure 3.4-6

As discussed in the preceding chapter, in the 2006 paper [Atlantic hurricanes and natural variability in 2005], Trenberth and Shea suggested that the preferred way to present the Atlantic Multidecadal Oscillation was to subtract the global sea surface temperature anomalies from those of the North Atlantic, as opposed to detrending the North Atlantic data. We can use that same method for the North Pacific sea surface temperature data to display the additional volatility of the North Pacific data. See Figure 3.4-6. The data in that graph have also been smoothed with a 121-month filter.

The additional variations in the sea surface temperatures of the North Pacific (compared to the global data) do enhance and suppress the variations in global sea surface temperatures, but those additional variations in the North Pacific are not in synch with the variations in global sea surface temperatures. In other words, during the two warming periods from the 1910s to the 1940s and from the mid-1970s to the early-2000s, the North Pacific can enhance or suppress that warming…and similarly, the North Pacific can enhance and suppress the cooling of global sea surface temperatures from the 1940s to the mid-1970s.

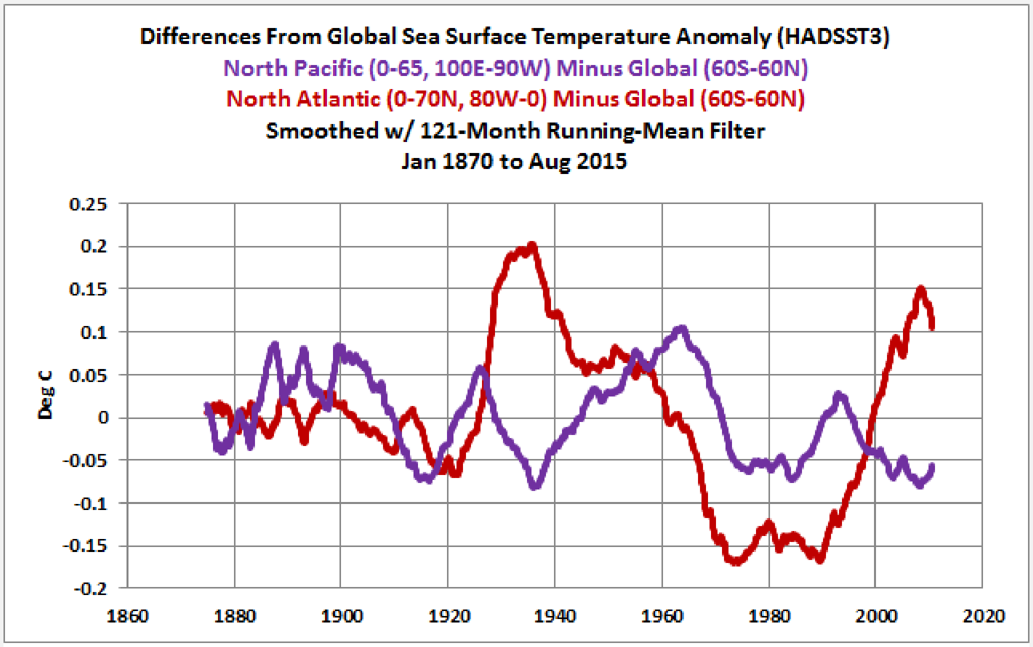


Figure 3.4-7

To reinforce the earlier illustrations and discussions, the additional variations in the sea surface temperatures of the North Pacific and North Atlantic (above and beyond those of the global data) are compared in Figure 3.4-7. In other words, I've subtracted the global data from the North Pacific and North Atlantic data, and then smoothed them with 121-month filters. It's very obvious that the two Northern Hemisphere ocean basins are not in synch and they can at times counteract one another. That is, since the mid-1990s, the sea surface temperatures of the North Atlantic have been warming faster than the global data, while the North Pacific had not. (But that changed recently, with The Blob and the 2015/16 El Niño. As shown, however, that doesn't make itself known when the data are smoothed with 121-month filters). The sea surface temperatures of the North Pacific had been suppressing global warming since the mid-1990s…again until recently. Refer again to General Discussions B and C for the discussions of the record high sea surface temperatures in 2014 and 2015.

NO AGREEMENT BETWEEN SEA SURFACE TEMPERATURE DATASETS

Under this heading, we're still discussing the additional variability of the sea surface temperatures of the North Pacific beyond that of the global data.   Looking at four long-term reconstructions, if we subtract the global sea surface temperature anomalies from the North Pacific data, Figure 3.4-8, we can see that there is little agreement between the four primary sea surface temperature datasets: NOAA's ERSST.v3b and ERSST.v4 and the UKMO's HADISST and HADSST3.

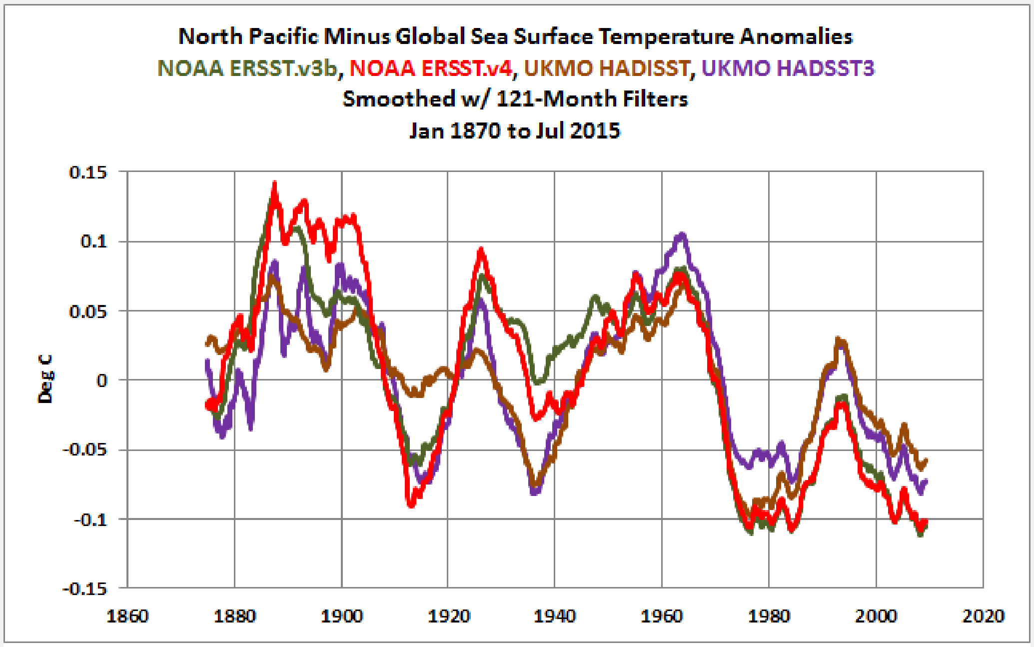


Figure 3.4-8

Before 1900, there is little agreement among the four. And while the breakpoints between the additional warming and cooling seem to coincide after 1900, the magnitudes of those variations are quite different. Then again, we're looking at differences of 0.05 deg C (0.09 deg F). Regardless, they impact the relative contributions of the North Pacific to their respective datasets. That lack of agreement between the four long-term sea surface temperature reconstructions might be another reason why the climate science community has ignored the additional variability of the North Pacific.

CORRELATION OF THE SEA SURFACE TEMPERATURES OF THE NORTH PACIFIC WITH SURFACE TEMPERATURES OF THE NORTHERN HEMISPHERE

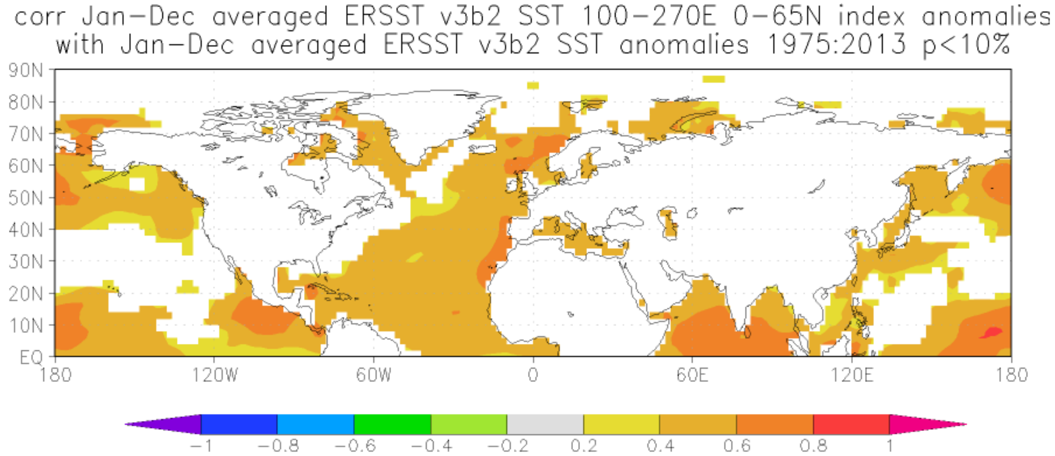
The following correlation maps (Figures 3.4-9, 3.4-10 and 3.4-11) show the correlation between the Northern Hemisphere surface temperature anomalies and the sea surface temperatures of the North Pacific for the period of 1975 to 2013. Figure 3.4-9 includes sea surface temperature data, Figure 3.4-10 is land surface air temperature data and Figure 3.4-11 includes the combined land-plus-sea surface temperature data. The sea surface temperature dataset is NOAA's ERSST.v3b. The land surface temperature data are from GISS. And the combined land+ocean data are based on the earlier version of this GISS Land-Ocean Temperature Index, when they used the ERSST.v3b data.

You'll notice that the correlation maps end in 2013. In other words, I haven't updated them from when I originally prepared this chapter last year. The reason: adding one more year of data (even with The Blob and the El Niño) does not change the correlation maps to an extent that would impact this very basic comparison. I'll confirm this for you in the discussion under the next heading.

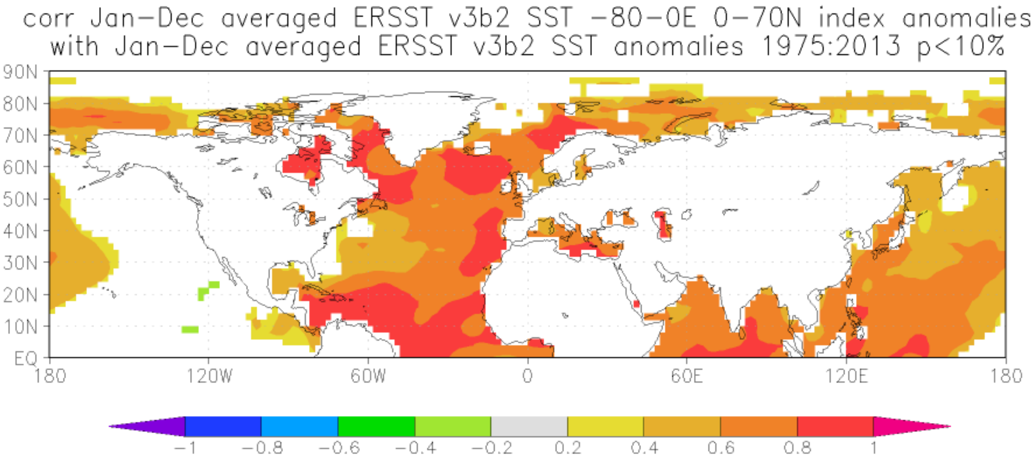
I've also included the correlations with the North Atlantic for the same period as a reference. It's pretty obvious why researchers focus their attention on the sea surface temperatures of the North Atlantic and not the North Pacific data. In addition to having the greater long-term variability, the North Atlantic sea surface temperatures correlate much better with land surface air temperatures than the North Pacific data.

Correlations of North Pacific And North Atlantic Sea Surface Temperatures With Northern Hemisphere Sea Surface Temperatures 1975 to 2013

North Pacific (0-65N, 100E-90W)



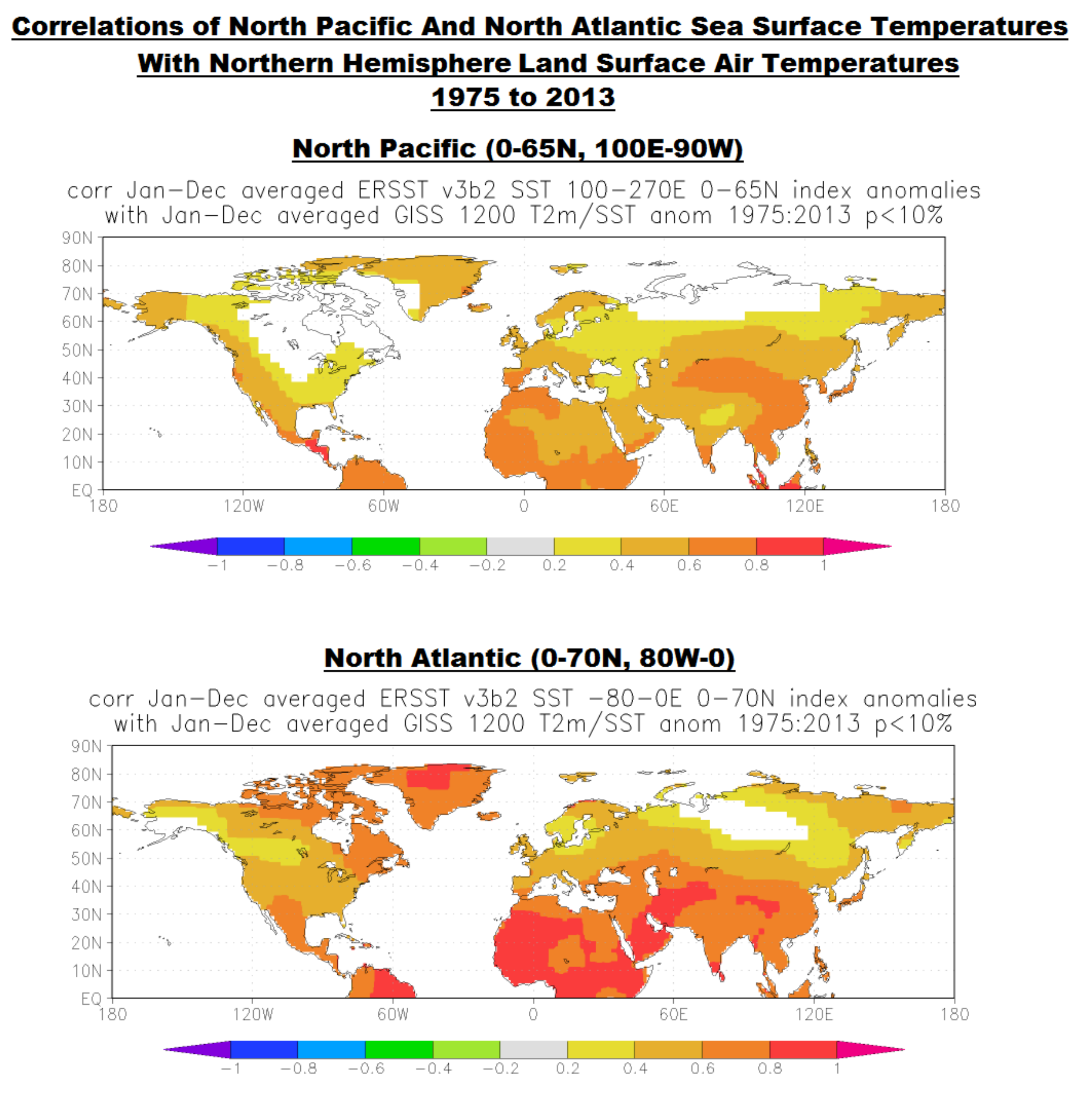
North Atlantic (0-70N, 80W-0)



Maps Created At KNMI Climate Explorer

Figure 3.4-9

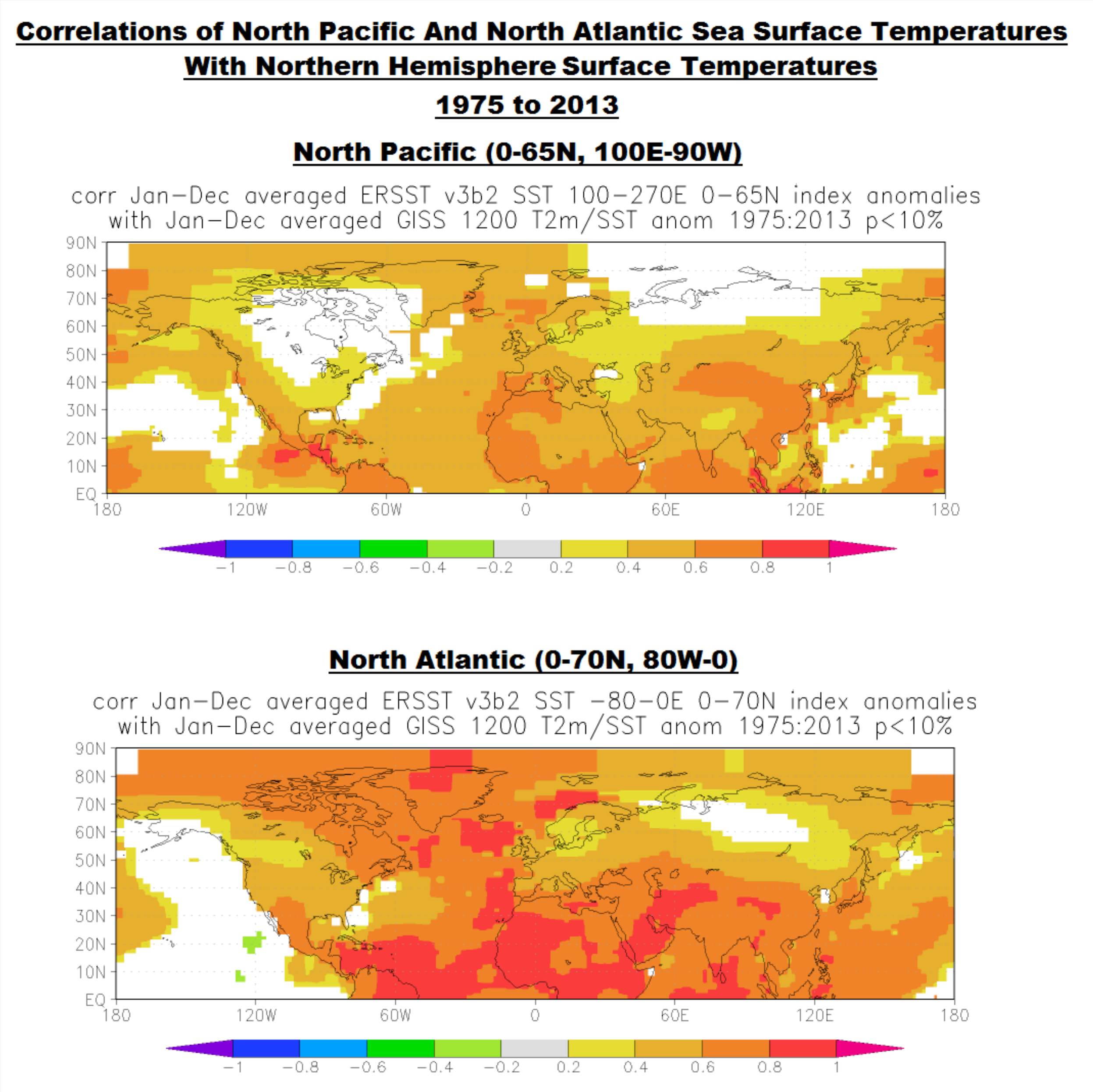
Keep in mind that the correlations of 0.40 to 0.6 are pretty bad. Anything less than that is horrible. Even correlations of 0.6 to 08 aren't that good, but they may be good enough for climate scientists to study the responses to see if there are any true relationships between the two.



Maps Created At KNMI Climate Explorer

Figure 3.4-10

# # #



Maps Created At KNMI Climate Explorer

Figure 3.4-11

CAUTIONARY NOTE: When looking at the correlation maps presented in climate science papers, always look at the scaling. I've used a full range of -1.0 to +1.0 in the above three sets of correlation maps. Many times scientific studies will use a lesser range like -0.7 to +0.7, which enhances the coloring and, if you're not paying attention to the scaling, makes the correlations appear better.

WHY DO SURFACE TEMPERATURES IN THE NORTHERN HEMISPHERE CORRELATE POORLY WITH THE NORTH PACIFIC SEA SURFACE TEMPERATURES?

The answer to the question lies in when and where the surface temperatures of the North Pacific warm and cool.

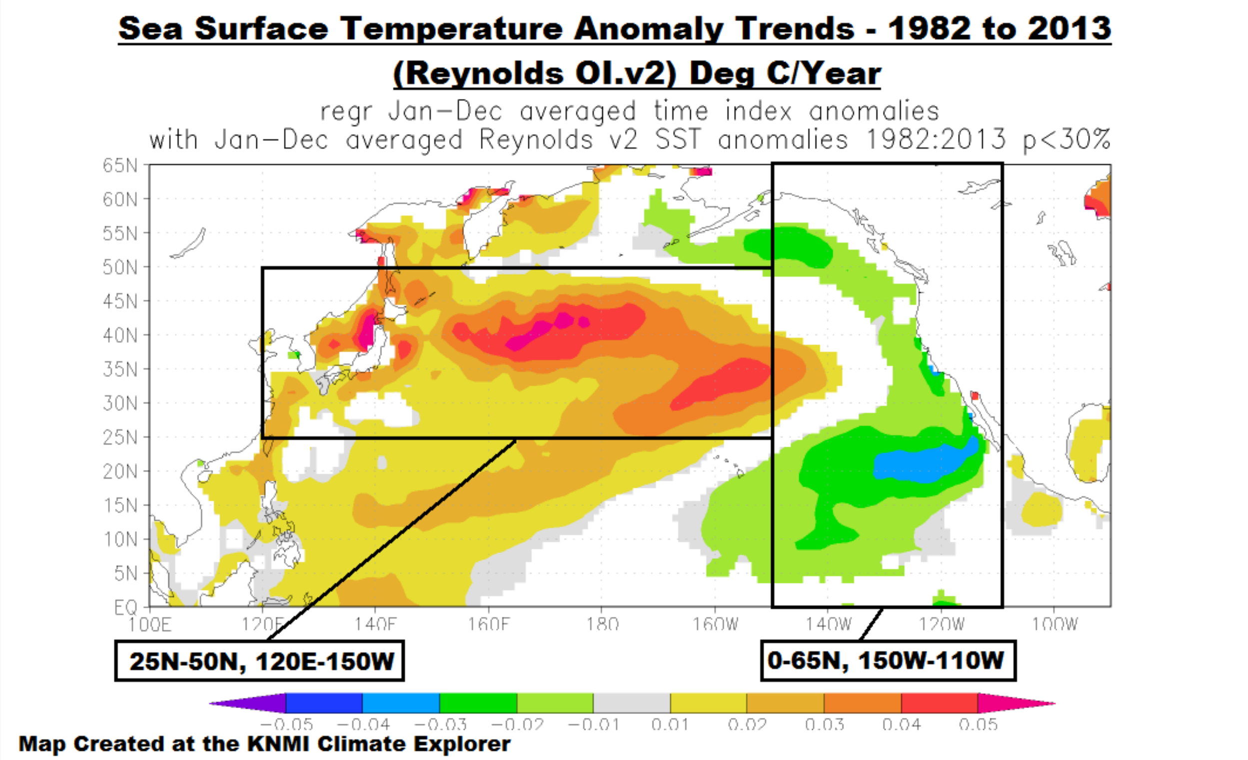


Figure 3.4-12

Figure 3.4-12 presents a map of the warming and cooling rates (the trends) of the sea surface temperature anomalies in the North Pacific during the satellite era…that is, from 1982 to 2013. For a change of pace we're using the NOAA's Optimum Interpolated satellite-enhanced sea surface temperature dataset (a.k.a. Reynolds OI.v2). That dataset starts in November 1981 and has excellent coverage of the global oceans. I've also included a supplemental version of Figure 3.4-12 that shows the trends from 1982 to 2014. The unusual warming event in the eastern extratropical North Pacific, known as The Blob, has reduced the cooling trend there.

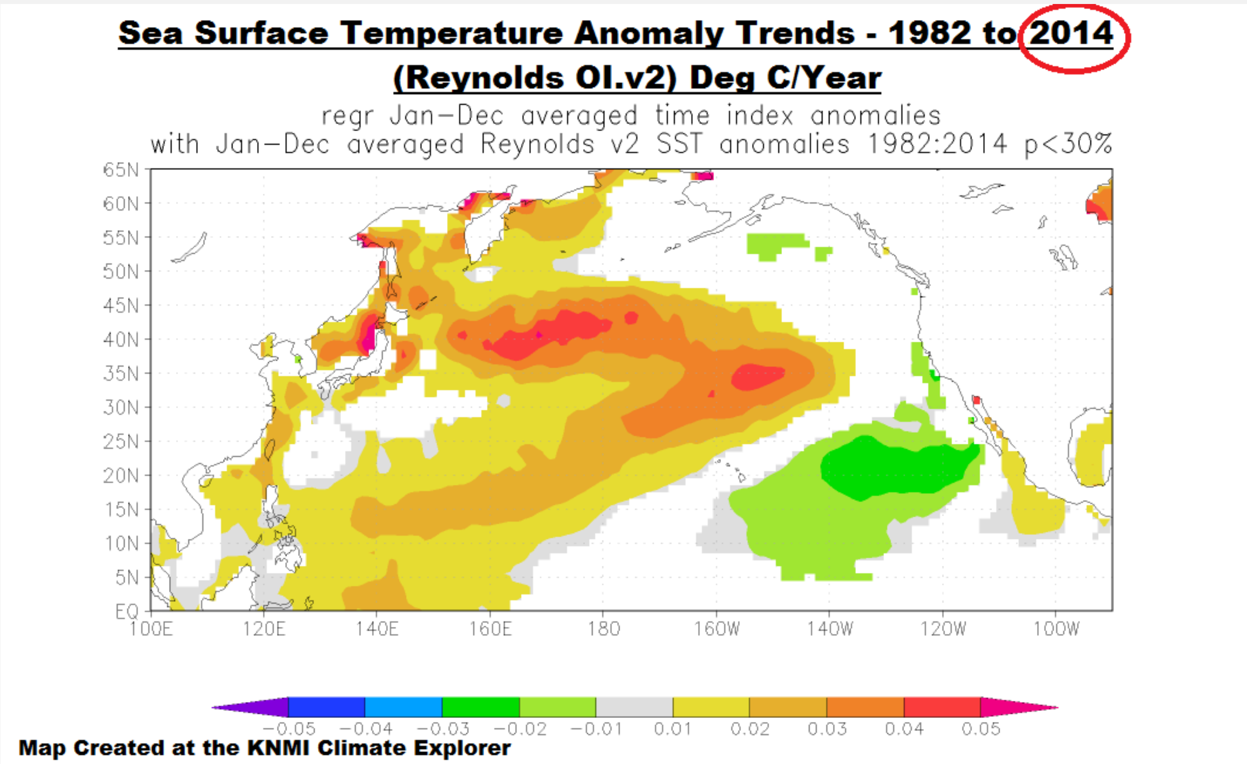


Figure 3.4-12 Supplement

In either map, we can see that the surface of the North Pacific has not warmed uniformly. Portions of the eastern North Pacific have cooled, while the west-central portion has warmed.

I've also highlighted two regions with the highest warming and cooling rates in Figure 3.4-12. They're the regions used for the following comparison graph of sea surface temperature anomalies, Figure 3.4-16. I've smoothed the data in that graph with 12-month running-average filters, because the data for the west-central portion are very volatile. Also, the volcanic aerosols from the eruptions of El Chichon in 1982 and Mount Pinatubo skew the data prior to 1995, but even so, we can see how the variations in the eastern portion are often counteracted by those in the west-central portion…but not always. We can see the sharp rise and fall of the sea surface temperature anomalies in the eastern portion in 1997/98. That spike is a response to the 1997/98 El Niño, which is often referred to as a "super" El Niño. There is a lag (a time lapse) of about a year between the warming in the east and the warming in the west-central portion, and by the time the west-central portion is warming, the eastern portion is cooling. Also standing out is the recent upswing due the combined effects of "The Blob" and the 2015/16 El Niño.

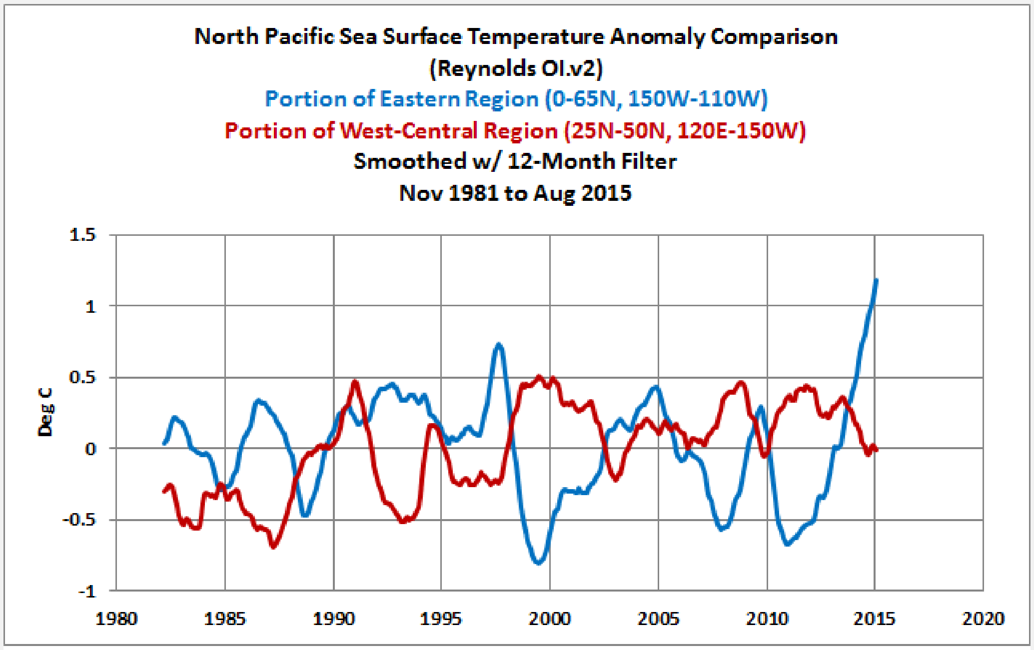


Figure 3.4-13

But notice how in Figure 3.4-13 the west-central portion does not cool proportionally afterwards in response to the La Niña event from 1998-2001, while the eastern portion does. There's a very simple reason for that curious effect, and we'll discuss it a few times throughout this book…not yet though.

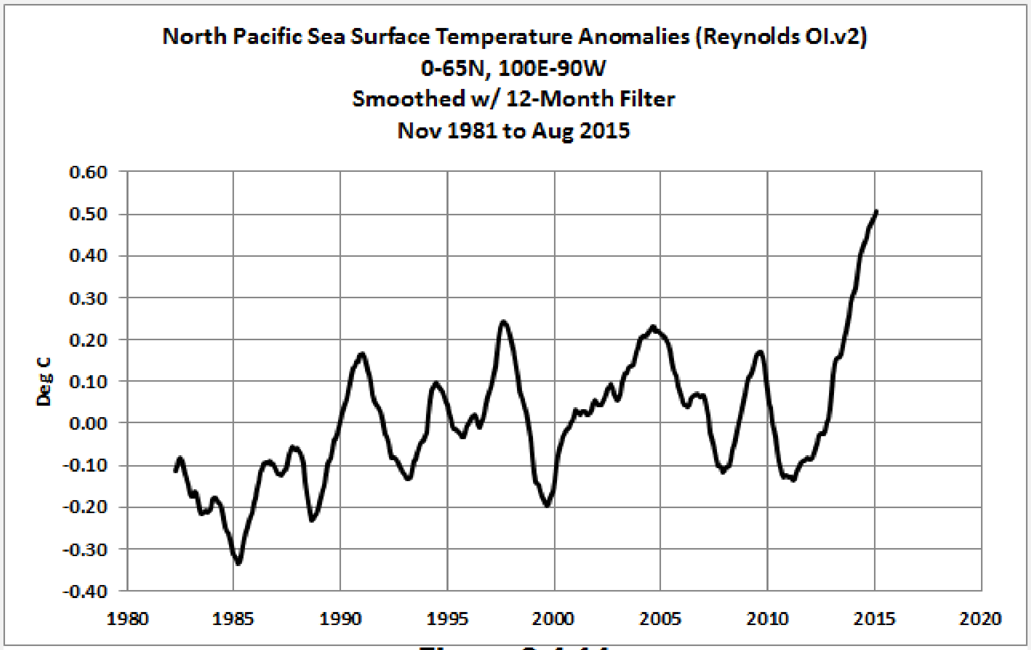


Figure 3.4-14

The eastern region and the west-central region of the North Pacific can run out-of-phase with one another, but not always, and, as a result, the variations in the surface temperatures of North Pacific as a whole, Figure 3.4-14, take on aspects of both regions.

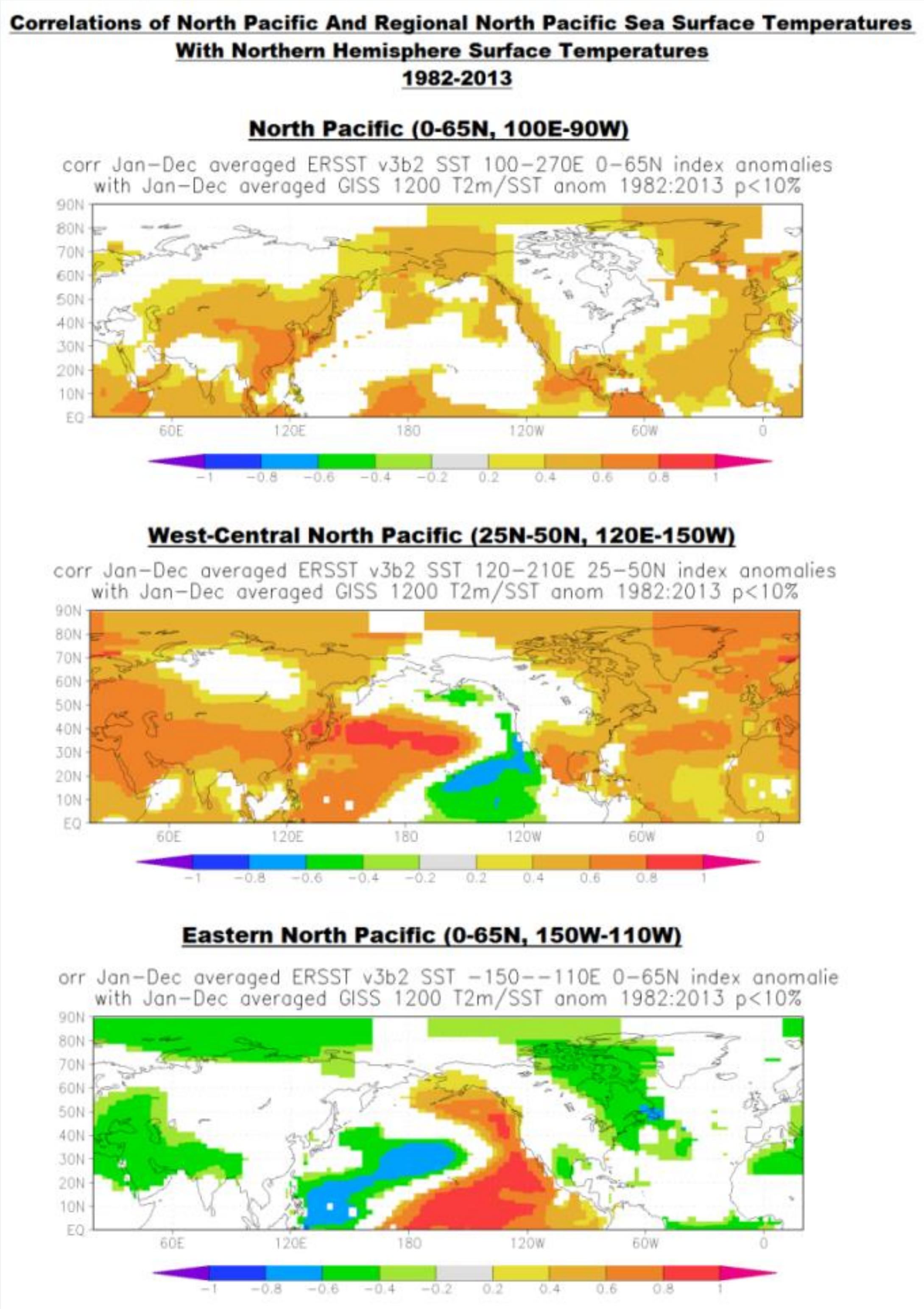
Now consider that the dominant causes of natural variations in surface temperatures around the globe on an annual basis are El Niño and La Niña events. Because the sea surface temperatures of the North Pacific are an odd combination of responses to El Niño and La Niña events, the sea surface temperatures of the North Pacific are not in phase with the rest of the world, where surface temperatures are responding to El Niño and La Niña events as one would expect.

There are 3 correlation maps in Figure 3.4-15. As noted earlier, the medium orange range of 0.4 to 0.6 is a poor correlation, so consider that while you're examining the maps. The top map presents the correlations of North Hemisphere surface temperatures with North Pacific sea surface temperatures. Even in the North Pacific, there are few regions that correlate well with the variations in the data for the entire North Pacific.

The correlations with the sea surface temperatures of the west-central portion of the North Pacific are much better throughout the Northern Hemisphere, as shown in the middle map.

The bottom map shows the correlations of Northern Hemisphere surface temperatures with the sea surface temperatures of the eastern portion of the North Pacific. Land surface temperatures throughout the Northern Hemisphere are negatively correlated (poorly) with the variations in the eastern portion of the North Pacific. The negative correlation indicates, when the surfaces of the eastern North Pacific warm, the surface temperatures cool in the parts of the Northern Hemisphere shown in greens and blues, and conversely, when the eastern North Pacific cools, those portions of the Northern Hemisphere warm.

One thing is certain: surface temperatures of the Northern Hemisphere correlate much better with the west-central portion of the North Pacific than they do with the eastern portion and with North Pacific as a whole.



Maps Created At KNMI Climate Explorer

Figure 3.4-15

NOTE: I've included a supplemental version of 3.4-15 in the following to show that adding another year of data has little impact on the correlations…even with The Blob in the eastern extratropical North Pacific. There are minor differences, but nothing that changes what we discussed. [End note.]

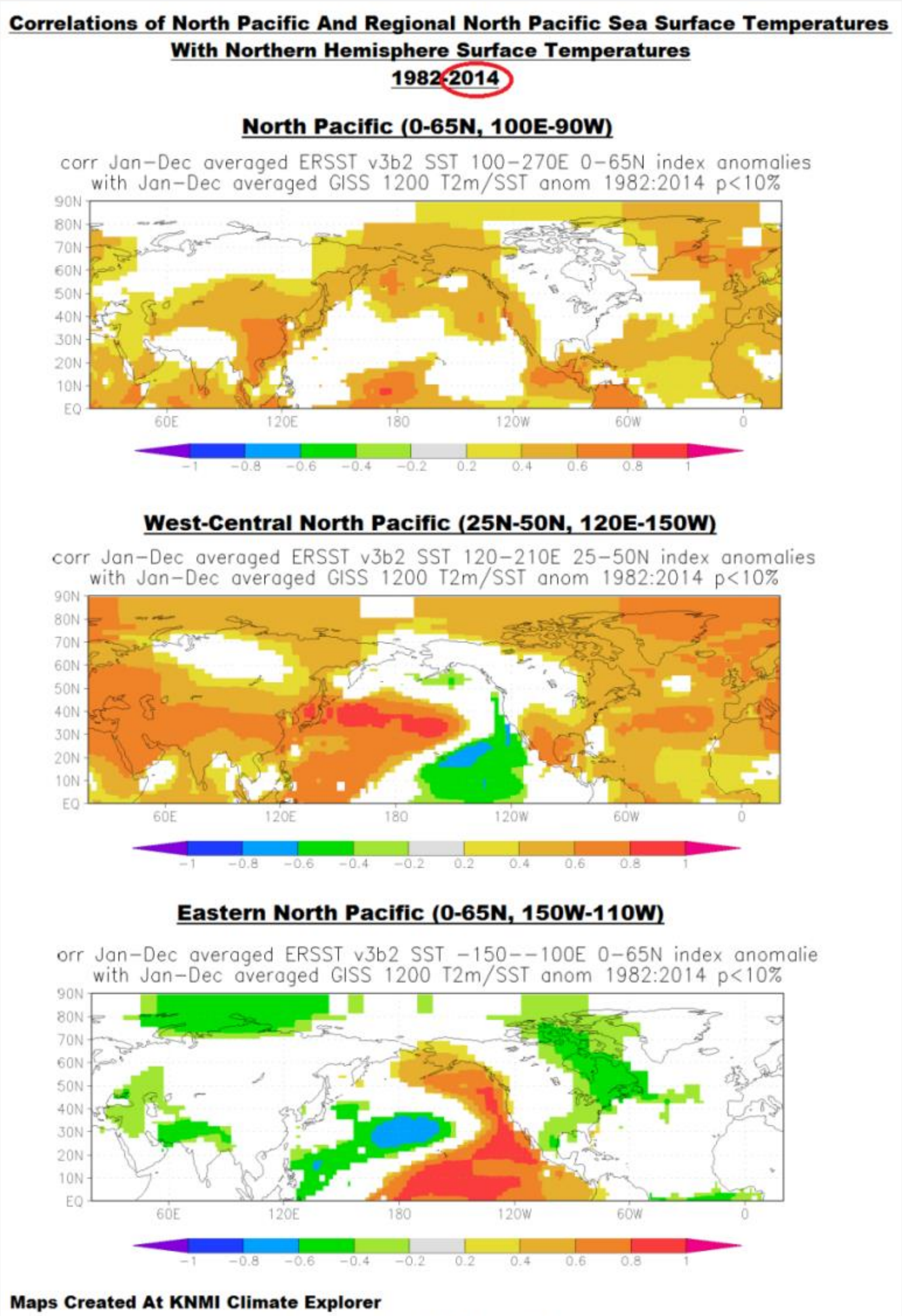


Figure 3.4-15 Supplement

WHAT DRIVES THE ADDITIONAL VARIABILITY IN THE SEA SURFACE TEMPERATURES OF THE NORTH PACIFIC?

Above, we illustrated and discussed that El Niño and La Niña events in the tropical Pacific have a large influence on the sea surface temperatures of the North Pacific. We'll discuss the processes that cause those variations in Chapter 3.7 – Ocean Mode: El Niño and La Niña. In addition, variations in sea level pressures in the North Pacific can cause sea surface temperatures there to change.

At first, you might wonder how the sea level pressure of an ocean basin or a part of an ocean basin might impact the sea surface temperatures there. The answer is relatively simple. Changes in sea level pressure reflect changes in the directions and strengths of surface winds, which we'll merge into the term "wind patterns", and wind patterns impact sea surface temperatures in many ways. The following are some examples.

Surface winds drive ocean currents, and ocean currents carry warm water from the tropics to higher latitudes and carry cool water from higher latitudes back to the tropics. The strength and direction of the surface winds can enhance or suppress general ocean circulation. Near the shores, surface winds contribute to upwelling and its counterpart downwelling. That is, certain wind patterns cause surface waters to move away from the coast, and at those times, those surface waters are replaced by cooler subsurface waters, which are drawn to the surface. The term upwelling applies to subsurface waters rising to the surface, and because subsurface waters are normally cooler than surface waters, upwelling causes the sea surface to cool along the shore. And the opposite can happen with other wind patterns; that is, certain wind patterns drive surface waters toward the coasts. At those times, the surface winds cause the surface waters to pile up along the coasts, which, in turn, cause the surface waters to sink. That process of surface waters sinking below the surface is known as downwelling.

With that in mind, we'll refer to a paper about the variations in the sea surface temperatures of the North Pacific. That paper is Trenberth and Hurrell (1994) Decadal Ocean-Atmosphere Variations in the Pacific. As a byproduct of that paper, the authors created a new sea level pressure index in the North Pacific called, logically, the North Pacific Index or NP. The UCAR North Pacific (NP) Index webpages include the following summary:

> *The North Pacific (NP) Index is the area-weighted sea level pressure over the region 30°N-65°N, 160°E-140°W. The NP index is defined to measure interannual to decadal variations in the atmospheric circulation. The dominant atmosphere-ocean relation in the north Pacific is one where atmospheric changes lead changes in sea surface temperatures by one to two months.*

> *However, strong ties exist with events in the tropical Pacific, with changes in tropical Pacific SSTs leading SSTs in the north Pacific by three months.*

In more general terms, Trenberth and Hurrell (1994) created the sea level pressure metric called the North Pacific (NP) Index to show how changes in atmospheric circulation (wind patterns) in the North Pacific impacted variations in sea surface temperatures. They found that changes in the sea level pressures of the North Pacific lead the changes in sea surface temperatures there by a couple of months. But, they've added that the variations in the tropical Pacific sea surface temperatures (which are associated with El Niño and La Niña events) also cause changes in the North Pacific sea surface temperatures, and that the changes in the tropical Pacific occur before the changes in North Pacific sea level pressures.

We'll discuss the North Pacific Index again in upcoming chapters because it is also critical in discussions of the Pacific Decadal Oscillation and in the ocean heat content of the North Pacific.

CHAPTER SUMMARY

Like the North Atlantic, there are decadal and multidecadal variations in the sea surface temperatures of the North Pacific that can enhance or suppress global warming. The multidecadal variations in the sea surface temperatures of the North Pacific are less than those of the North Atlantic and can run in and out of phase with the North Atlantic. Surface temperatures in the Northern Hemisphere correlate better with the sea surface temperatures of the North Atlantic than with those of North Pacific.

3.5 – Ocean Mode: Pacific Decadal Oscillation

INITIAL NOTE: Much of this chapter was taken from my April 2014 blog post The 2014/15 El Niño – Part 5 – The Relationship Between the PDO and ENSO.

# # #

The term Pacific Decadal Oscillation (a.k.a. PDO) is used for a number of different modes of variability. This is very unfortunate, because using the same term for different things is confusing to many people, especially those new to the discussion of global warming and climate change. Pacific Decadal Oscillation is used to represent:

- the multidecadal variations in the sea surface temperatures of the North Pacific, which we discussed in the previous chapter,
- the decadal and multidecadal variations in the strengths, frequencies and magnitudes of El Niño and La Niña events, which we'll discuss in an upcoming chapter and
- the multidecadal variations in the spatial patterns of the sea surface temperatures of the North Pacific.

This chapter discusses the last of those three, which is the classic definition of the Pacific Decadal Oscillation. And to help clarify what the Pacific Decadal Oscillation represents, we'll spend a lot of time discussing what it doesn't represent.

The term Pacific Decadal Oscillation was coined back in 1996, about 2 decades ago, by Stephen Hare during the preparation of a paper about regional salmon-fishing productivity along the west coast of North America. The paper was Mantua et al. (1997) A Pacific interdecadal climate oscillation with impacts on salmon production. The abstract is here. In that paper, Pacific Decadal Oscillation was used to describe the variations in the spatial patterns of sea surface temperature anomalies of the North Pacific (not the variations in the sea surface temperatures themselves).

A few years later, a dataset was prepared to represent the Pacific Decadal Oscillation (the spatial pattern version), but it was the product of another paper, by another group of authors: Zhang et al. (1997) ENSO-like Interdecadal Variability: 1900–93. That data are maintained by the Joint Institute for the Study of the Atmosphere and Ocean (JISAO). JISAO is a joint venture between the University of Washington (UW) and NOAA.

Because the term is used in different ways, when newcomers look for information about the Pacific Decadal Oscillation, they usually wind up at the JISAO Pacific Decadal Oscillation website, where they will learn what I'll call the classic definition of the PDO. But the authors of a paper or blog post may be using the term Pacific Decadal Oscillation to describe something totally different—the multidecadal variations in the sea surface temperatures of the North Pacific or the variations in the frequencies, strengths and durations of El Niño events.

So you have to be very careful when reviewing a paper or blog post that uses the term Pacific Decadal Oscillation or PDO. You first have to determine which mode of variability the author is discussing.

Then there is another problem, and this relates to blog posts primarily. Some authors haven't the slightest idea what the Pacific Decadal Oscillation data represent. And that adds even more confusion for people new to the topic of global warming and climate change.

Again, this chapter relates to the classic definition of the Pacific Decadal Oscillation, which is a variation in the spatial patterns of the sea surface temperature anomalies of the extratropical North Pacific (north of 20N).

THE PACIFIC DECADAL OSCILLATION IS A USEFUL INDEX

This chapter is not intended to suggest, in any way, that the Pacific Decadal Oscillation Index is not a useful dataset. It was born as a tool for the Pacific fishing industry. I also understand that the Pacific Decadal Oscillation index is used by meteorologists for forecasting weather in North America. With that in mind…

WHAT THE PACIFIC DECADAL OSCILLATION DATA DO AND DO NOT REPRESENT

The Pacific Decadal Oscillation index data are available from the JISAO Pacific Decadal Oscillation website. The Pacific Decadal Oscillation index represents the spatial pattern of the sea surface temperature anomalies in the extratropical North Pacific (20N-65N)…not the sea surface temperature anomalies themselves. A strong positive Pacific Decadal Oscillation index value indicates the sea surface temperature anomalies of the eastern extratropical North Pacific are warmer than the western and central portions, which is a spatial pattern created by El Niño events. See Figure 3.5-1. On the other hand, a strong negative Pacific Decadal Oscillation index value indicates the sea surface temperature anomalies of the western and central portions of the extratropical North Pacific are warmer than the eastern portion, and that's a spatial pattern created by La Niña events. The spatial patterns shown in Figure 3.5-1 are independent of the actual sea surface temperature of that extratropical portion of the North Pacific.

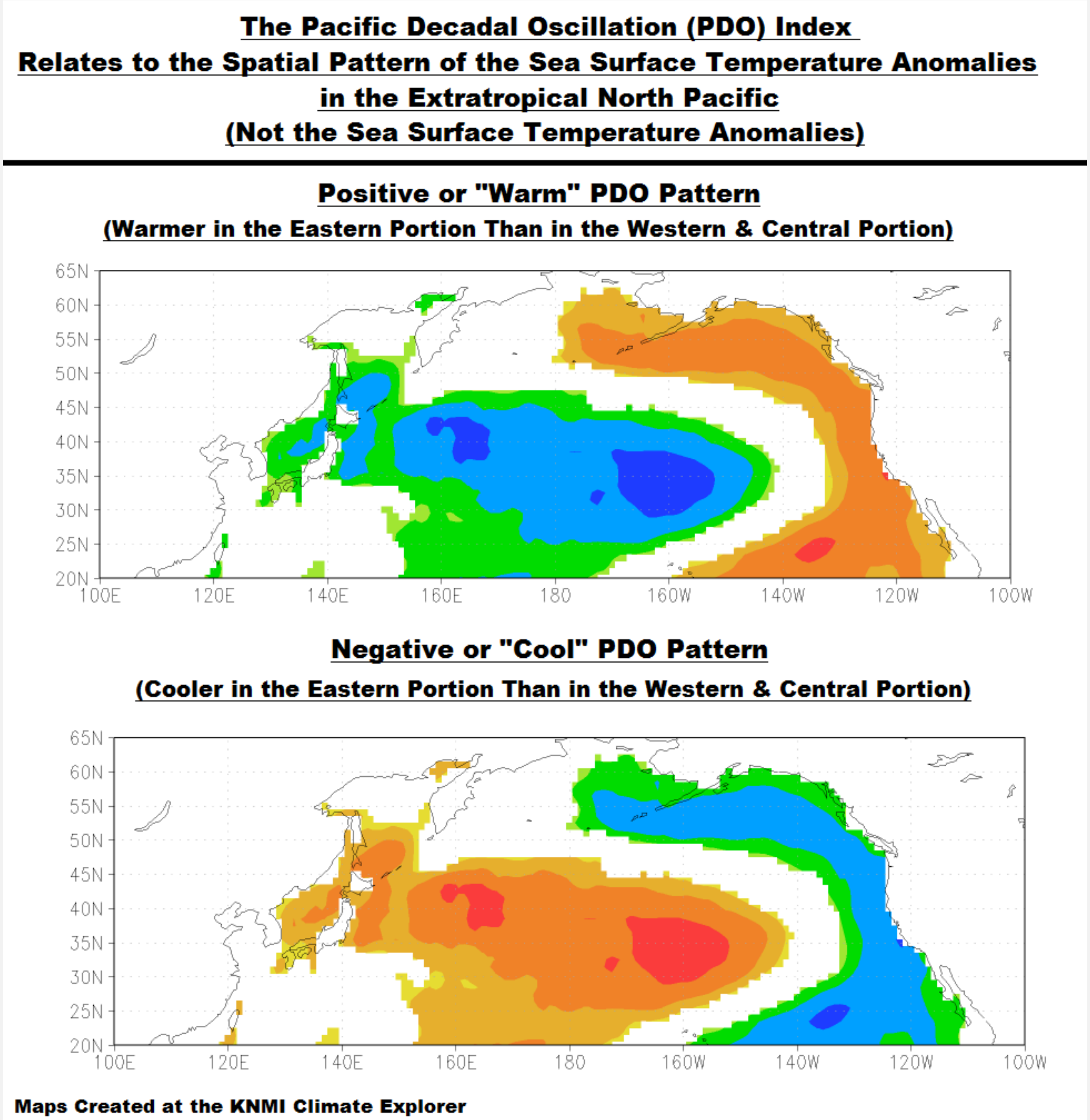


Figure 3.5-1

Studies of salmon production (fishing) in the early 1990s noted abrupt changes in productivity that lasted for multidecadal periods. These changes in salmon production were tied to the climate of the North Pacific Ocean. The term "Pacific Decadal Oscillation" was coined in the mid-1990s as a result of that research.

The method for calculating the Pacific Decadal Oscillation index data was first presented in a 1997 paper by Zhang et al. ENSO-like Interdecadal Variability: 1900–93.

In that paper, the Pacific Decadal Oscillation is referred to as NP, for extratropical North Pacific poleward of 20N.   There's a very important quote from Zhang et al. (1997) and we'll discuss it later in the chapter.

You'll notice that the maps in Figure 3.5-1 include only the extratropical North Pacific (20N-65N), that they exclude the tropical North Pacific. The reason: El Niños and La Niñas take place in the tropical Pacific, so climate scientists use the extratropical North Pacific for the Pacific Decadal Oscillation index data to minimize the direct influence of El Niño and La Niña events on the Pacific Decadal Oscillation data.

As noted earlier, the Pacific Decadal Oscillation index data is maintained by the Joint Institute for the Study of the Atmosphere and Ocean (JISAO). See their Pacific Decadal Oscillation (PDO) webpage, and their Pacific Decadal Oscillation index Monthly Values webpage for data. When reviewing the JISAO Pacific Decadal Oscillation webpage, consider that the latest paper on that webpage is from the year 2000 and that the webpage is dated that same year. Much has changed in the understanding of the Pacific Decadal Oscillation since then.

WARM AND COOL PHASES OF THE PACIFIC DECADAL OSCILLATION

The use of the words “warm” and “cool” when discussing the phases of the Pacific Decadal Oscillation may lead to some confusion. “Warm” and “cool” are tied to the phase of the eastern portion of the North Pacific, and how the eastern portion relates to the western-central portion, not the actual surface temperature of the entire extratropical North Pacific. That is, when the Pacific Decadal Oscillation is in the “warm” phase, the eastern portion of the North Pacific (north of 20N) is warmer than the west-central portion, and vice versa for the “cool” phase.

Consider this when thinking of the Pacific Decadal Oscillation index data and its “warm” and “cool” phases. It's a simple way to establish that the Pacific Decadal Oscillation does not relate to the overall surface temperatures of the North Pacific. A cooling of the sea surface temperature anomalies of the western-central portion of the North Pacific can cause the Pacific Decadal Oscillation index to increase, but an increase in the Pacific Decadal Oscillation can also be caused by a warming of the sea surface temperatures of the eastern North Pacific. In the first example, the surface temperatures of the entire North Pacific would have cooled, and in the second, they would have warmed, but the values of the Pacific Decadal Oscillation index increased in both examples. Further, as we'll illustrate later in the post, the Pacific Decadal Oscillation index agrees better with the opposing variations western-central portion than it does with the alike-direction changes in the eastern portion.

SPATIAL PATTERNS CREATED BY EL NIÑO AND LA NIÑA EVENTS

Let’s discuss what the Pacific Decadal Oscillation represents in more detail: A La Niña event in the tropical Pacific typically creates a spatial pattern in the extratropical North Pacific where it’s cooler in the eastern portion than it is in the western and central portions. See the top cell of Figure 3.5-2.

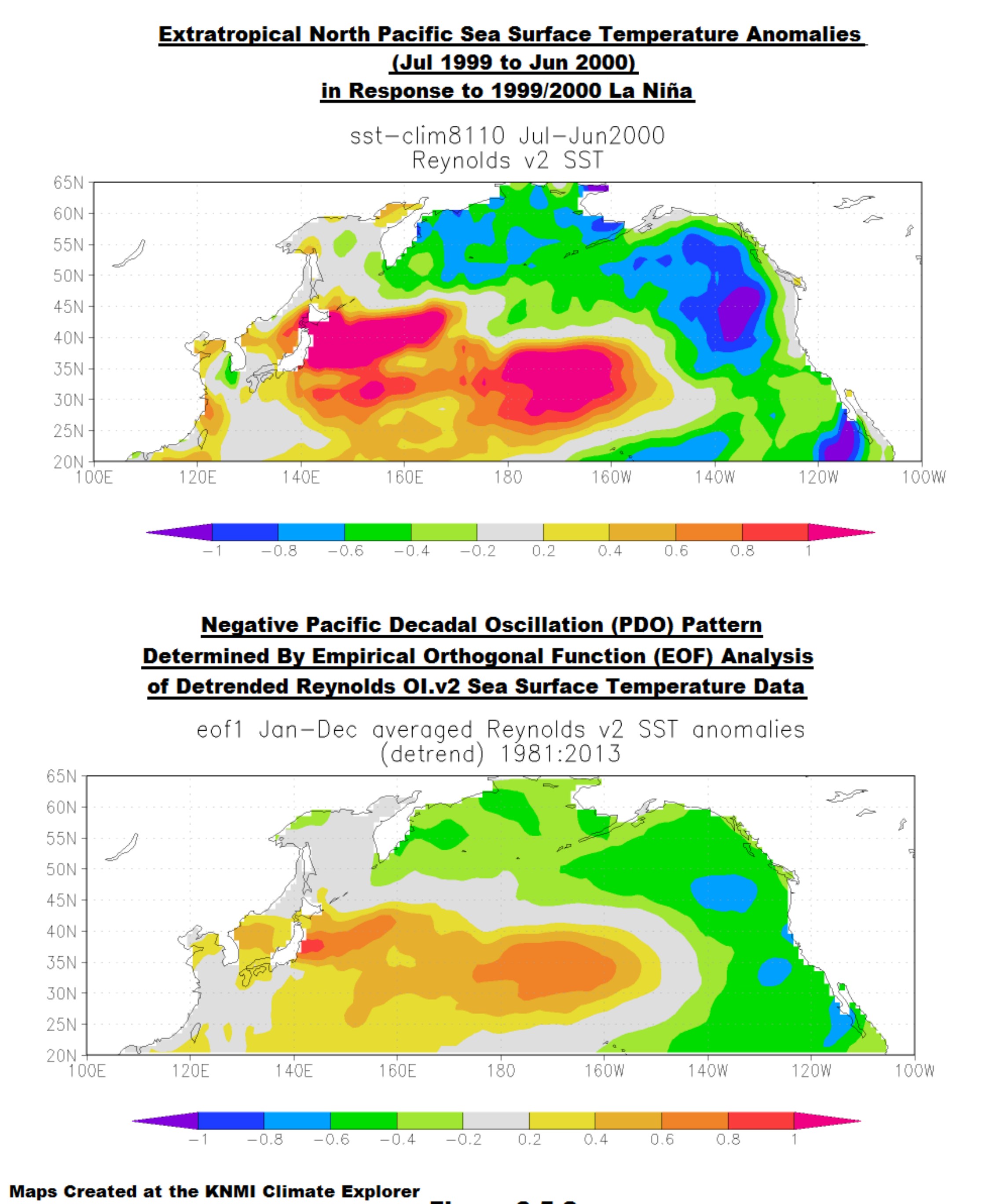


Figure 3.5-2

I've excluded the tropical Pacific, where the La Niña is taking place, to focus this conversation on the extratropical North Pacific, where the Pacific Decadal Oscillation spatial pattern is observed. The top cell illustrates the average sea surface temperature anomalies of the extratropical North Pacific for the period of July 1999 to June 2000. That's a full year of the multiyear 1998-01 La Niña. July to June is used because La Niñas normally peak in boreal winter. The dataset is NOAA's satellite-enhanced Reynolds OI.v2 sea surface temperature data. Note how it's cooler in the eastern North Pacific than it is in the western and central portions. That's a textbook spatial pattern in the extratropical North Pacific caused by a La Niña. It's also a classic "cool" Pacific Decadal Oscillation spatial pattern, which is shown in the bottom map of Figure 3.5-2.

An El Niño event creates the opposite spatial pattern, where it's warmer in the eastern extratropical North Pacific and cooler in the western and central portions, and that also relates to a "warm" Pacific Decadal Oscillation spatial pattern.

It is often said that the Pacific Decadal Oscillation pattern is the dominant spatial pattern in the extratropical North Pacific, and that makes sense because the Pacific Decadal Oscillation pattern represents the El Niño- and La Nina-like pattern in the extratropical North Pacific…and…El Niños and La Niñas are the dominant mode of natural variability for the global oceans.

HOW THE PACIFIC DECADAL OSCILLATION DATA ARE CALCULATED

The Pacific Decadal Oscillation data are not sea surface temperature data of the North Pacific. The Pacific Decadal Oscillation data, however, are determined from the sea surface temperature data there, using statistical analyses called Empirical Orthogonal Function (EOF) analysis and Principal Component Analysis, which are interrelated and used to determine two things. The Empirical Orthogonal Function analysis determines the dominant spatial pattern in the extratropical North Pacific sea surface temperature anomalies and we can see that pattern on maps. Principal Component analysis creates a time-series data that basically represents how closely, at any given time, the spatial pattern resembles the dominant spatial pattern.

Note the distinction. Once again: the Pacific Decadal Oscillation data are determined from the sea surface temperature data of the North Pacific, but they do not represent the sea surface temperatures there. Now, I'm not intentionally trying to make this difficult to understand, but that's the reality of the Pacific Decadal Oscillation index data. The Pacific Decadal Oscillation index data is the 1st Principal Component (PC1) of the sea surface temperature anomalies of the extratropical North Pacific (north of 20N)…after the global sea surface temperature anomalies are subtracted from the North Pacific sea surface temperature anomaly data in each 5-deg latitude by 5-deg longitude grid. One more step: The 1st Principal Component is then standardized (divided by its standard deviation) to create the Pacific Decadal Oscillation data. And in the case of the Pacific Decadal Oscillation, the standardization greatly amplifies the variability of the Pacific Decadal Oscillation, making the Pacific Decadal Oscillation index appear more significant than it really is. The scaling of the Pacific Decadal Oscillation will be confirmed later in this chapter.

So the Pacific Decadal Oscillation data are a very abstract form of the sea surface temperatures of the extratropical North Pacific.

It may be easiest to think of the Pacific Decadal Oscillation data in another way—as representing how closely the spatial pattern in the North Pacific at any point in time matches the spatial pattern created by La Niña and El Niño events. If the spatial pattern roughly resembles the La Niña pattern in Figure 3.5-2, then the Pacific Decadal Oscillation index value would be negative. As the spatial pattern comes closer to matching the one created by La Niña events, the PDO index value grows more negative. And the opposite holds true for the El Niño-related spatial pattern. As the spatial pattern comes closer to matching the one created by El Niño events, the PDO index value grows more positive.

For the bottom map in Figure 3.5-2 above, I used the Empirical Orthogonal Function analysis (EOF1) feature of the KNMI Climate Explorer, with the Reynolds OI.v2 sea surface temperature data. (Note: I took a shortcut with that map. Instead of removing the global data from each grid, I simply had the software in the KNMI Climate Explorer detrend the North Pacific sea surface temperature data. The results are close enough for this discussion.) So the bottom map in Figure 3.5-2 presents a classic cool Pacific Decadal Oscillation pattern, which would be represented by a negative Pacific Decadal Oscillation index value.

A zero Pacific Decadal Oscillation index value indicates that La Niña-related or El Niño-related patterns do not exist at that time.

ANOTHER WAY TO VIEW THE RELATIONSHIP BETWEEN THE PACIFIC DECADAL OSCILLATION AND THE SEA SURFACE TEMPERATURES OF THE NORTH PACIFIC

Let's consider that La Niña-related (cool-Pacific Decadal Oscillation) spatial pattern from Figure 3.5-2, which shows up in the Pacific Decadal Oscillation index as a negative value. The actual sea surface temperatures of the North Pacific can rise and fall, but just as long as that spatial pattern remained fixed (cooler in the east and warmer in the west and central North Pacific) the Pacific Decadal Oscillation index would remain at a constant negative value. While it's not determined this way, sometimes it's easier to think of the Pacific Decadal Oscillation as a temperature difference between the eastern extratropical North Pacific and the western and central portions.

Again, it's very important to understand that the Pacific Decadal Oscillation index does not relate to the actual sea surface temperature anomalies of the North Pacific (north of 20N). The Pacific Decadal Oscillation index value only relates to the spatial pattern there.

We'll confirm this again later in the chapter, using data.

WHERE THE PACIFIC DECADAL OSCILLATION DATA COMES FROM

Note also that only the extratropical North Pacific is presented in Figure 3.5-2. The Pacific Decadal Oscillation data are derived from sea surface temperature data in that location and that location only. The Pacific Decadal Oscillation data do not represent the tropical Pacific or the El Niño and La Niña events that take place in the tropical Pacific. The Pacific Decadal Oscillation data also do not represent the Pacific Ocean as a whole.

THE PACIFIC DECADAL OSCILLATION SPATIAL PATTERNS ARE ALSO IMPACTED BY WINDS

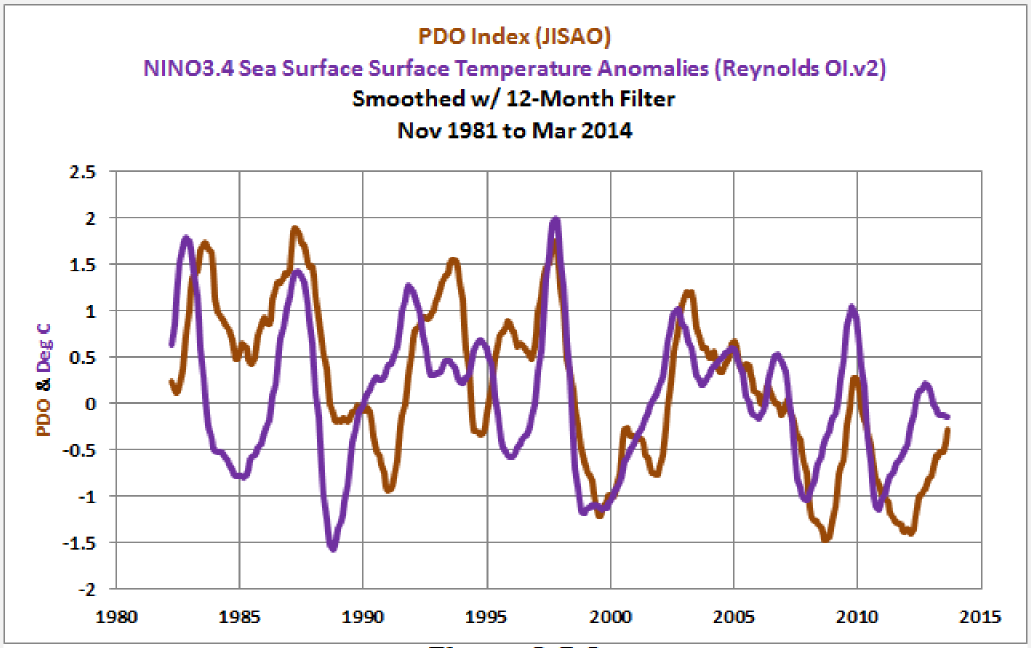


Figure 3.5-3

Figure 3.5-3 is a time-series graph that presents the Pacific Decadal Oscillation index data and the Reynolds OI.v2 satellite-enhanced sea surface temperature anomalies for the NINO3.4 region. The NINO3.4 region sea surface temperature anomalies are a commonly used index for the timing, strength and duration of El Niño and La Niña events. The El Niños are the large upward spikes in the sea surface temperature anomalies of the NINO3.4 region of the equatorial Pacific, and the La Niñas are the downward ones. The NINO3.4 data have not been standardized, but the Pacific

Decadal Oscillation index has been. In the case of the Pacific Decadal Oscillation, the standardization multiplies its year-to-year variations. So the standardization greatly exaggerates the importance of the Pacific Decadal Oscillation index. The monthly Pacific Decadal Oscillation index data are quite volatile (see the graph here) so both datasets have been smoothed with 12-month running-mean filters in Figure 3.5-3.

You'll note that the two datasets run in and out of agreement. That indicates that not every La Niña (El Niño) creates a classic La Nina-like (El Niño-like) spatial pattern in the extratropical North Pacific.

The reason that the Pacific Decadal Oscillation index does not mimic an ENSO index at all times is the spatial patterns of the sea surface temperatures in the North Pacific are also affected by the sea level pressures (and the related variations in wind patterns) there. (We'll confirm this in the next section.) That is, the sea level pressures and the strength and direction of the winds (basically weather) in the extratropical North Pacific can suppress or enhance the El Niño-like or La Niña-like spatial patterns there. That causes the year-to-year and the multidecadal variations in the Pacific Decadal Oscillation index to be different than those of an ENSO index. The differences in the annual variability can be seen above in Figure 3.5-3, and the differences in the multidecadal variations between the two indices can be seen below in Figure 3.5-4.

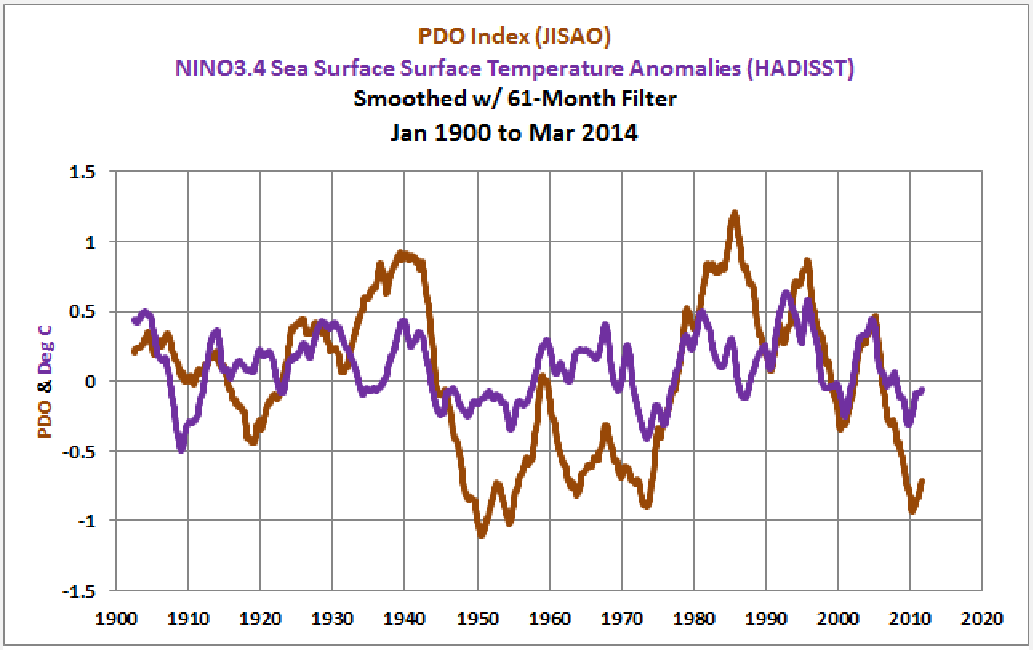


Figure 3.5-4

Figure 3.5-4 compares a long-term ENSO index (NINO3.4 sea surface temperature anomaly data based on the HADISST dataset) to the long-term monthly Pacific Decadal Oscillation index. Both datasets have been smoothed with 61-month filters to suppress the year-to-year variations and to highlight the differences in their multidecadal variations. (See the monthly long-term Pacific Decadal Oscillation and NINO3.4 data here.) It's very obvious that ENSO and Pacific Decadal Oscillation data both show long-term variations. The smoothed NINO3.4 data indicate that there are decadal and multidecadal variations in the strengths, frequency and durations of El Niño and La Niña events. And the smoothed Pacific Decadal Oscillation index shows that there are decadal and multidecadal variations in the El Niño- and La Niña-like spatial patterns in the extratropical North Pacific. Because the sea level pressures and wind patterns in the extratropical Pacific also have decadal and multidecadal variations, the Pacific Decadal Oscillation index does not track the ENSO index over these timeframes.

The Japan Meteorological Agency (JMA) webpage Explanation of the Pacific Decadal Oscillation (PDO) also confirms this interrelationship between the Pacific Decadal Oscillation and the North Pacific sea surface temperatures and sea level pressures. There, they write:

> *In the North Pacific, the atmosphere and the ocean display a trend of co-variance with aperiod [sic] of about 20 years. This variability is called the Pacific Decadal Oscillation (PDO).*
>
> *Supposing that SSTs are lower than their normals in the central part of the North Pacific, they are likely to be higher than their normals both in the eastern part of the North Pacific and in the equatorial Pacific. This seesaw pattern varies slowly, and appears repeatedly with a period of about 20 years. In this case, the Aleutian Low and the jet stream in the upper troposphere tend to be strong. The North Pacific Index (NPI) is utilized as an indicator for the strength of the Aleutian Low.*

We'll discuss the North Pacific Index under the next heading.

To confirm that the Pacific Decadal Oscillation index is a product of the spatial pattern of the sea surface temperature anomalies of the extratropical North Pacific and sea level pressure, refer to NOAA's Pacific Decadal Oscillation (PDO) teleconnections webpage. There they write (my boldface):

> *The Pacific Decadal Oscillation (PDO) is often described as a long-lived El Niño-like pattern of Pacific climate variability (Zhang et al. 1997). As seen with the better-known El Niño/Southern Oscillation (ENSO), extremes in the PDO pattern are marked by widespread variations in the Pacific Basin and the North American climate. In parallel with the ENSO phenomenon, the extreme phases of the PDO have been classified as being either warm or cool, as defined by ocean temperature anomalies in the northeast and tropical Pacific Ocean.* ***When SSTs are anomalously cool in the interior North Pacific and warm along the Pacific Coast, and when sea level pressures are below average over the North Pacific, the PDO has a positive value. When the climate anomaly***

patterns are reversed, with warm SST anomalies in the interior and cool SST anomalies along the North American coast, or above average sea level pressures over the North Pacific, the PDO has a negative value (Courtesy of Mantua, 1999).

This long-term variability of the Pacific Decadal Oscillation and its relationship with El Niño and La Niña events in the equatorial Pacific is easier to see with multiyear filters…as shown above in Figure 3.5-4. On monthly and annual timescales, the variations in the Pacific Decadal Oscillation data can, at times, be remarkably similar to those of the ENSO index, as shown in Figure 3.5-3 above, and at times they can be quite different.

THE NORTH PACIFIC INDEX (NPI) AND ITS RELATIONSHIP WITH THE PACIFIC DECADAL OSCILLATION

The North Pacific Index was introduced in the 1994 Trenberth and Hurrell paper Decadal Ocean-Atmosphere Variations in the Pacific. The UCAR North Pacific (NP) Index webpages include the following summary, which confirm our understandings so far of the Pacific Decadal Oscillation:

> *The North Pacific (NP) Index is the area-weighted sea level pressure over the region 30°N-65°N, 160°E-140°W. The NP index is defined to measure interannual to decadal variations in the atmospheric circulation. The dominant atmosphere-ocean relation in the north Pacific is one where atmospheric changes lead changes in sea surface temperatures by one to two months. However, strong ties exist with events in the tropical Pacific, with changes in tropical Pacific SSTs leading SSTs in the north Pacific by three months.*

The monthly North Pacific Index data from UCAR are here. They are also available in anomaly form through the Monthly climate indices webpage at the KNMI Climate Explorer, under the heading of “Teleconnection patterns” (through August 2012). Looking at the monthly North Pacific Index anomalies, the Pacific Decadal Oscillation index and the NINO3.4 sea surface temperature anomalies during the satellite era of sea surface temperatures, it’s hard to imagine any relationships between the North Pacific Index data and the other two indices. See Figure 3.5-5. Smoothing all three datasets with 12-month filters doesn’t seem to help much either, as shown in Figure 3.5-6.

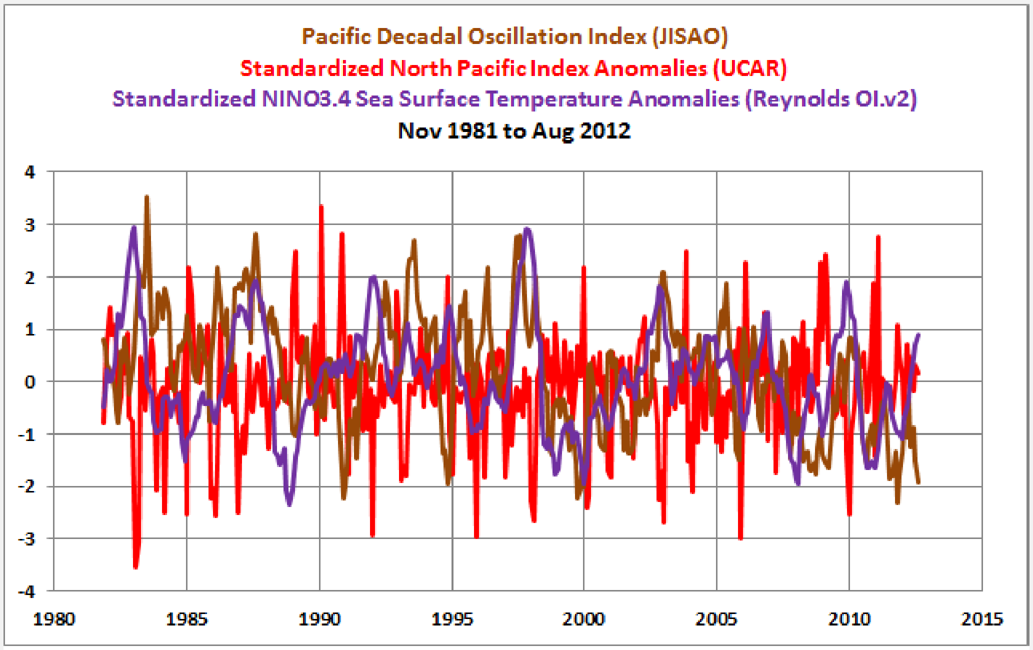


Figure 3.5-5

# # #

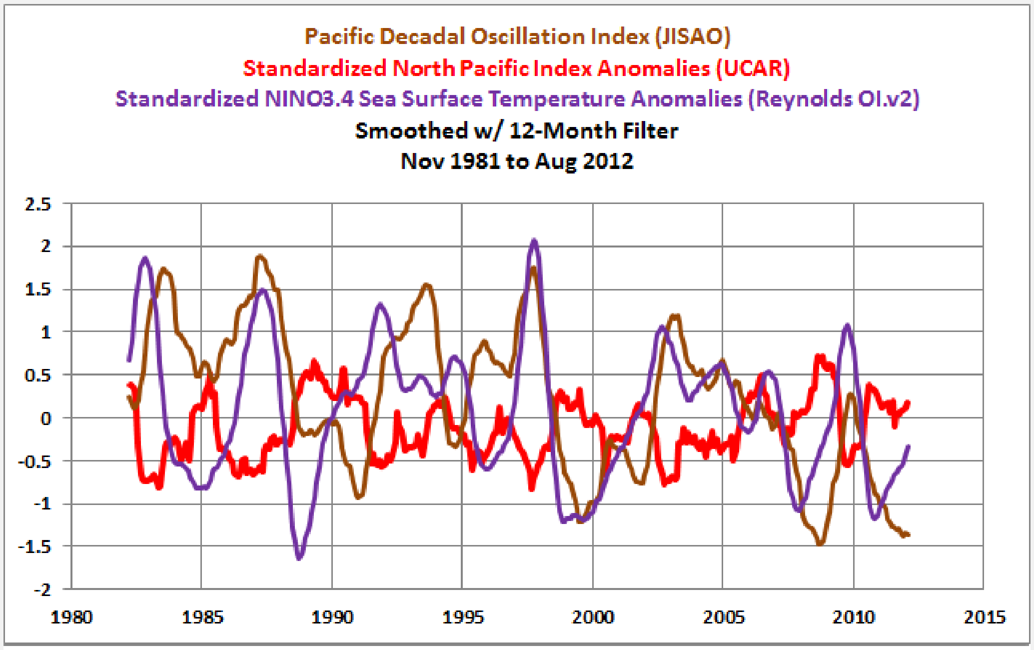


Figure 3.5-6

So 5 years ago, I presented a very simply way to show the relationship between the North Pacific Index data and the other two variables. (That post is here.) I subtracted the Pacific Decadal Oscillation index data from standardized NINO3.4 sea surface temperature anomalies, and compared that difference to the North Pacific Index data, where the difference and the North Pacific Index data were both smoothed with multiyear filters. The long-term variations mimicked one another reasonably well after the 1920s—then again, how reliable are the data before then. In Figure 3.5-7, for a change of pace, I used Kaplan SST-based NINO3.4 data and smoothed the data with 121-month filters.

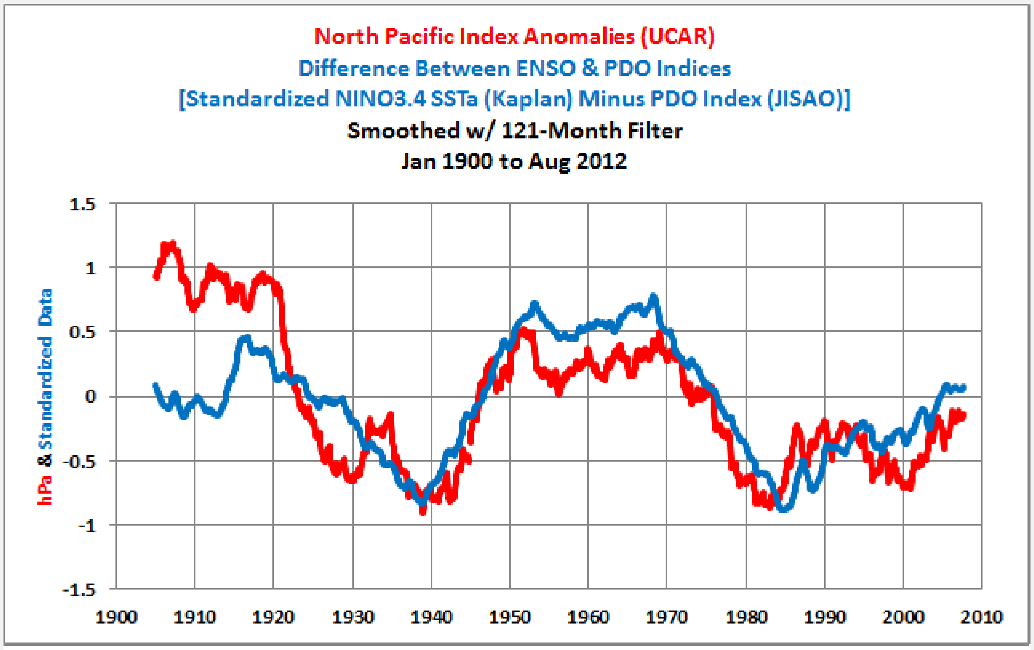


Figure 3.5-7

The multidecadal variations in the North Pacific Index (sea level pressure) mimic the difference between the ENSO and Pacific Decadal Oscillation indices from the early 1920s to present. Considering how sparse the data are before the early 1920s, the divergence then is not unexpected.

Figure 3.5-8 presents two correlation maps for the satellite era of sea surface temperatures. I've had to shorten the time span of the data because the North Pacific Index ends mid-year of 2012 at the KNMI Climate Explorer. The top map shows the correlation between the North Pacific Index and the sea surface temperature anomalies of the extratropical North Pacific. The North Pacific Index creates a weak Pacific Decadal Oscillation-like pattern. And in the bottom map is the correlation between NINO3.4 sea surface temperature anomalies (our ENSO index) and the sea surface temperature data for the same region. ENSO creates a strong Pacific Decadal Oscillation-like pattern.

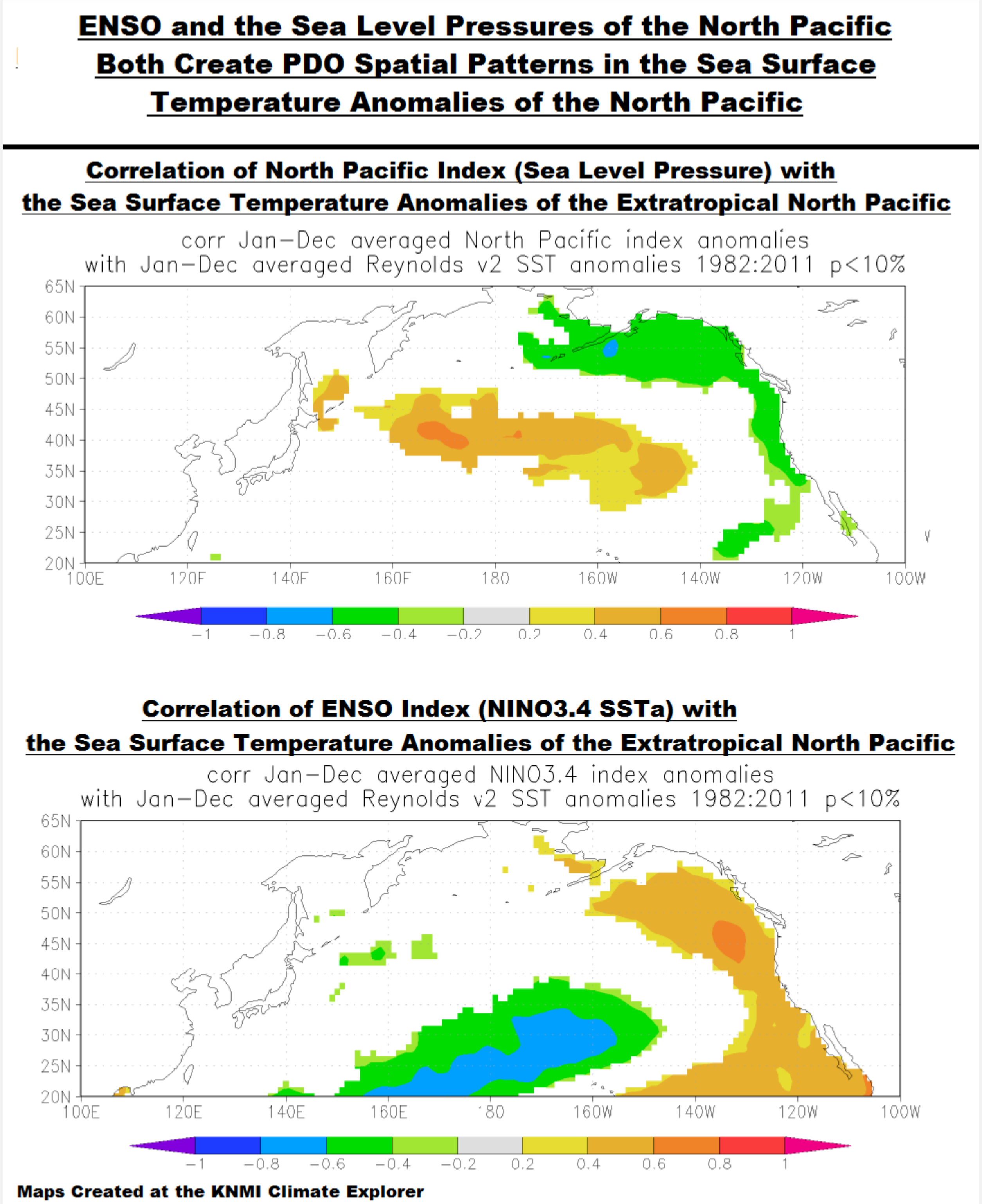


Figure 3.5-8

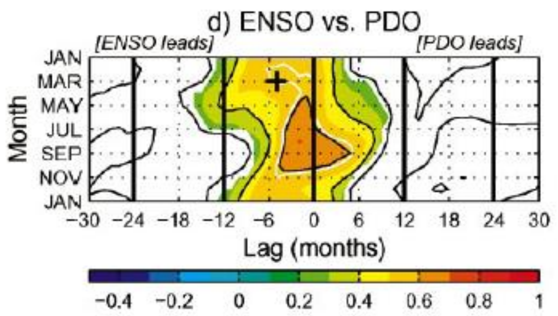
That pretty much confirms our earlier quote from the NOAA Pacific Decadal Oscillation (PDO) teleconnections webpage. That is, I believe it's safe to say that the difference between the long-term variations in the Pacific Decadal Oscillation and ENSO is related to the sea level pressure of the North Pacific as expressed by the North Pacific Index (and interrelated wind patterns), and that ENSO dominates over the sea level pressure on short-term timescales.

"THE PDO IS DEPENDENT UPON ENSO ON ALL TIMESCALES"

The heading is a quote from the concluding comments of the Newman et al. (2003) ENSO-Forced Variability of the Pacific Decadal Oscillation. In other words, ENSO (El Niño and La Niña events) drives the Pacific Decadal Oscillation, not the other way around.

Figure 3.5-9 is cell d of Figure 1 from Newman et al. (2003). It's a different way to present correlation, showing the correlations between two variables (ENSO and PDO) for months of the year (vertical-axis/y-axis) for different time lags (horizontal-axis/x-axis). ENSO leads the PDO when the lag values are negative, and the PDO leads ENSO when the lag values are positive.

Figure 1d From Newman et al (2003)



Annual cycle of cross correlation between ENSO and the PDO. The PDO leads ENSO for positive lags; ENSO leads the PDO for negative lags. The month ordinate refers to the PDO; e.g., the cross represents correlation between Mar PDO and Oct (lag −5) ENSO. The thin white line is the 0.58 contour. Correlations are for the period 1950–2001, and contour (fill) interval is 0.2 (0.1). Only values that are at least 90% significant are shaded.

Figure 3.5-9

The Newman et al. (2003) discussion of that illustration reads:

> *ENSO also leads the Pacific Decadal Oscillation index by a few months throughout the year (Fig. 1d), most notably in winter and summer. Simultaneous correlation is lowest in November– March, consistent with Mantua et al. (1997). The lag of maximum correlation ranges from two months in summer (r ~ 0.7) to as much as five months by late winter (r ~ 0.6). During winter and spring, ENSO leads the PDO for well over a year, consistent with reemergence of prior ENSO-forced PDO anomalies. Summer PDO appears to lead ENSO the following winter, but this could be an artifact of the strong persistence of ENSO from*

> *summer to winter (r = 0.8), combined with ENSO forcing of the PDO in both summer and winter. Note also that for intervals less than 1yr the lag autocorrelation of the PDO is low when the lag autocorrelation of ENSO (not shown) is also low, through the so-called spring persistence barrier (Torrence and Webster 1998).*

Basically, they're saying that the variations in El Niño and La Niña events in the tropical Pacific typically happen before the variations in the Pacific Decadal Oscillation.

PDO-Related Cell From Figure 7 of Zhang et al. (1997)

(CT = ENSO Index, NP = PDO index)

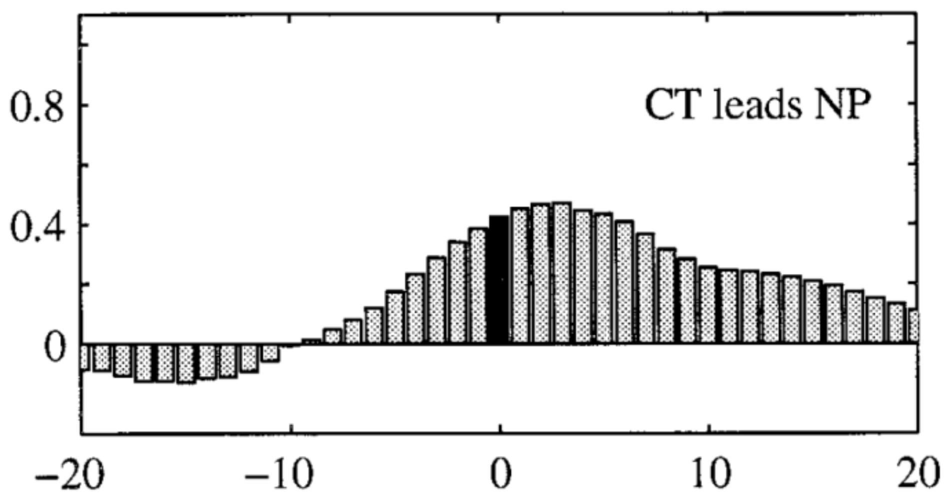


FIG. 7. Cross-correlation functions between the cold tongue index and the time series in Fig. 5, based on unfiltered data. The *x* axis represents the lag in months, where positive values indicate that CT is leading the other time series.

Figure 3.5-10

This also agrees with the findings of the paper that first presented the Pacific Decadal Oscillation: Zhang et al. (1997) ENSO-like Interdecadal Variability: 1900–93. Recall that Zhang et al. refer to the Pacific Decadal Oscillation as "NP". For an ENSO index, they used the Cold Tongue Index (CT) in place of NINO3.4 sea surface temperature anomalies, which are more commonly used now. The Cold Tongue Index represents sea surface temperature anomalies of the region bordered by the coordinates of 6S-6N, 180-90W, where NINO3.4 region occupies 5S-5N, 170W-120W. In the bottom cell of Figure 7 of Zhang et al., shown here as Figure 3.5-10, they illustrate the cross-correlation functions between their ENSO index and the Pacific Decadal Oscillation. As illustrated in the original Pacific Decadal Oscillation paper, the authors note that the NP (PDO) lags CT (ENSO) by approximately 3 months.

Bottom line for this heading: the Pacific Decadal Oscillation is an aftereffect of El Niño and La Niña events…but the Pacific Decadal Oscillation is also impacted by the sea level pressures and related wind patterns of the North Pacific.

IF THE PACIFIC DECADAL OSCILLATION LAGS ENSO, THEN THE PACIFIC DECADAL OSCILLATION CANNOT DRIVE ENSO

There are a multitude of posts and comments around the blogosphere that state something to the effect of "during a warm Pacific Decadal Oscillation (a multidecadal period when the Pacific Decadal Oscillation is positive), El Niño events are more frequent, and during a cool Pacific Decadal Oscillation (a multidecadal period when the Pacific Decadal Oscillation is negative), La Niña events are more frequent." Expressed in that way, those comments lead people to believe that the Pacific Decadal Oscillation drives the frequencies, strengths and durations of El Niño and La Niña events. Because the Pacific Decadal Oscillation lags ENSO, the warm or cool phase of the Pacific Decadal Oscillation cannot drive the strength, frequency and duration of El Niño and La Niña events. It's the other way around, "the Pacific Decadal Oscillation is dependent upon ENSO on all timescales". The persons making the claims that the Pacific Decadal Oscillation is the driver of ENSO have cause and effect reversed, and they forget to account for the addition variability of the Pacific Decadal Oscillation caused by variations in sea level pressures and wind patterns.

-HOWEVER-

This does not mean that the sea surface temperatures of the North Pacific do not provide feedback to the tropical Pacific. Unfortunately, the Pacific Decadal Oscillation index does not represent the sea surface temperatures of the North Pacific. And the Pacific Decadal Oscillation index correlates poorly with the sea surface temperature anomalies of the eastern extratropical North Pacific.

THE PACIFIC DECADAL OSCILLATION INDEX IS NOT AN ENSO INDEX

We cannot look at the Pacific Decadal Oscillation index and always determine if an El Niño or La Niña is occurring in the tropical Pacific. Sometimes, yes…but not always. The same holds true in the other direction: we cannot look at an ENSO index and assume the North Pacific will always have an El Niño-like spatial pattern during an El Niño, or a La Niña-like spatial pattern during a La Niña. Here are a few examples.

Figure 3.5-11 presents the monthly satellite-era comparison of the Pacific Decadal Oscillation index and NINO3.4 sea surface temperature anomalies (an ENSO index). In

November 1994, the Pacific Decadal Oscillation index was showing a strong negative value (suggesting a La Niña), while the sea surface temperatures of the NINO3.4 region are indicating a moderate El Niño was taking place.

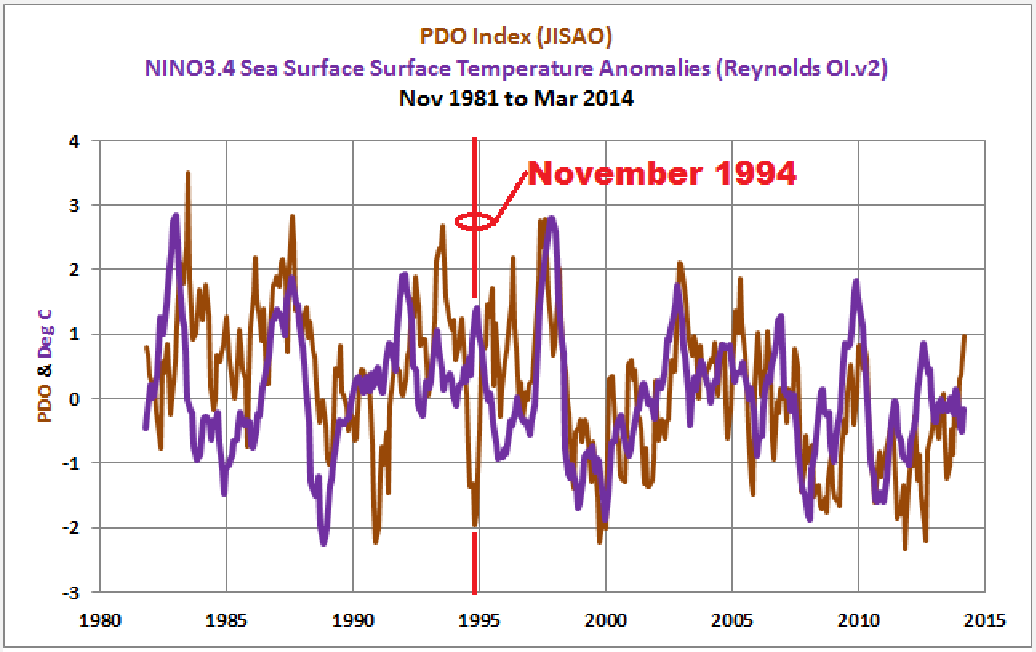


Figure 3.5-11

The sea surface temperature anomaly map of the tropical Pacific and the extratropical North Pacific in Figure 3.5-12 confirm both realities. The tropical Pacific is showing an El Niño event and the extratropical North Pacific is showing a “cool” Pacific Decadal Oscillation pattern, where it’s warmer in the western-central North Pacific than it is in the eastern North Pacific.

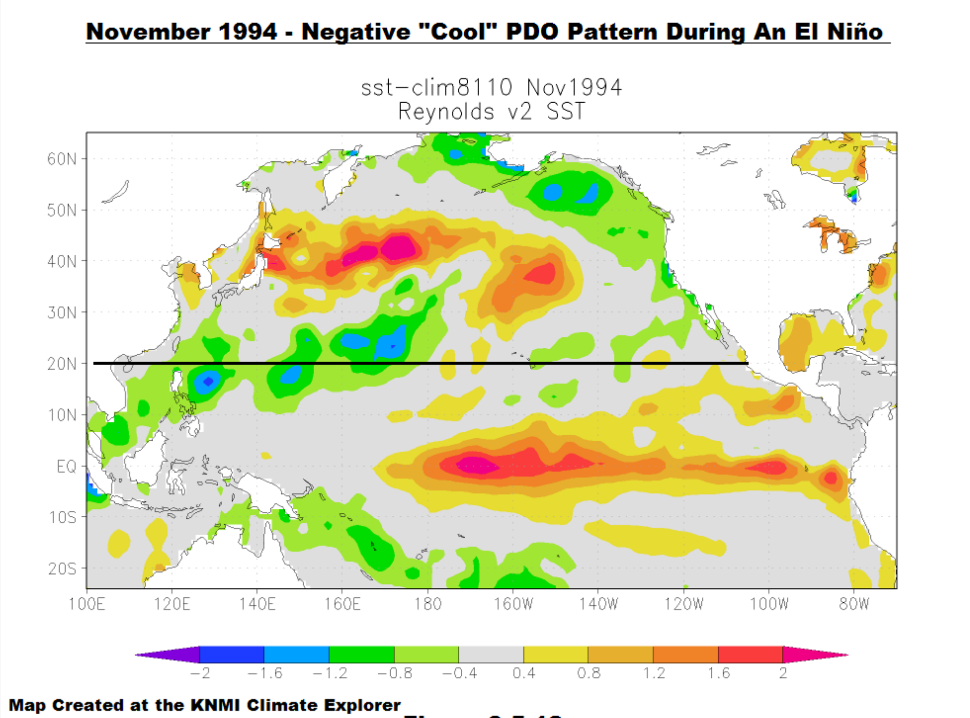


Figure 3.5-12

A good example of the reverse situation is a little more difficult to find, but we'll settle on May 1996. See Figure 3.5-13, where I've highlighted that month in the time-series comparison. The Pacific Decadal Oscillation index peaks at a relatively high value in May 1996, while the ENSO index is showing ENSO neutral conditions, but leaning toward La Niña.

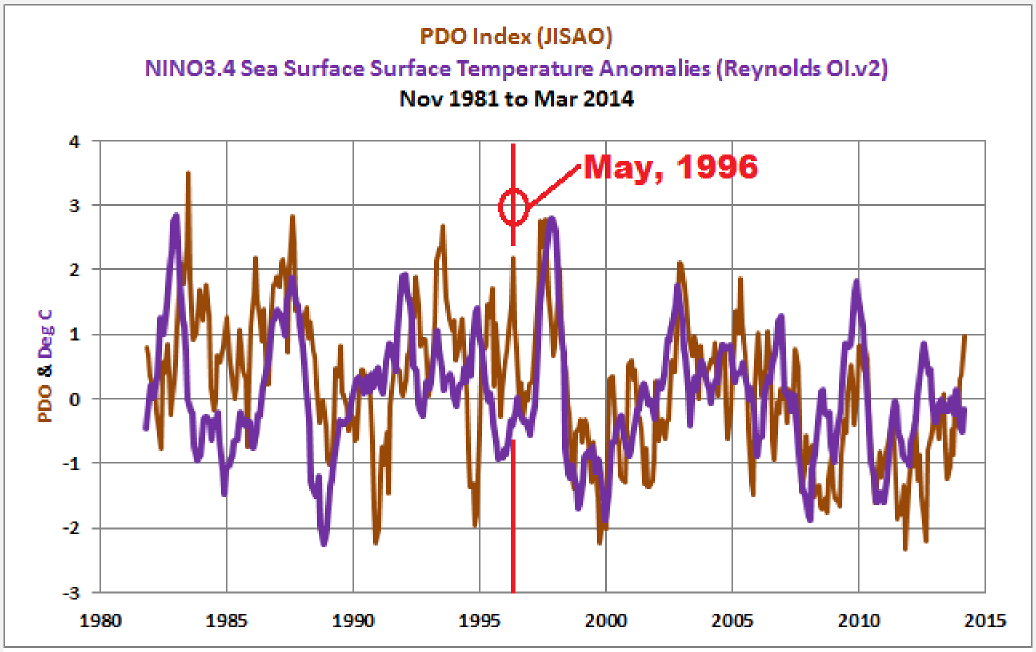


Figure 3.5-13

And we can confirm both realities with the sea surface temperature anomaly map for May 1996. See Figure 3.5-14. There is a warm PDO pattern in the extratropical North Pacific, while there are ENSO-neutral conditions (but leaning toward La Niña conditions) in the tropical Pacific.

And that confirms the heading for this topic. The Pacific Decadal Oscillation (PDO) Index cannot be used as an ENSO index.

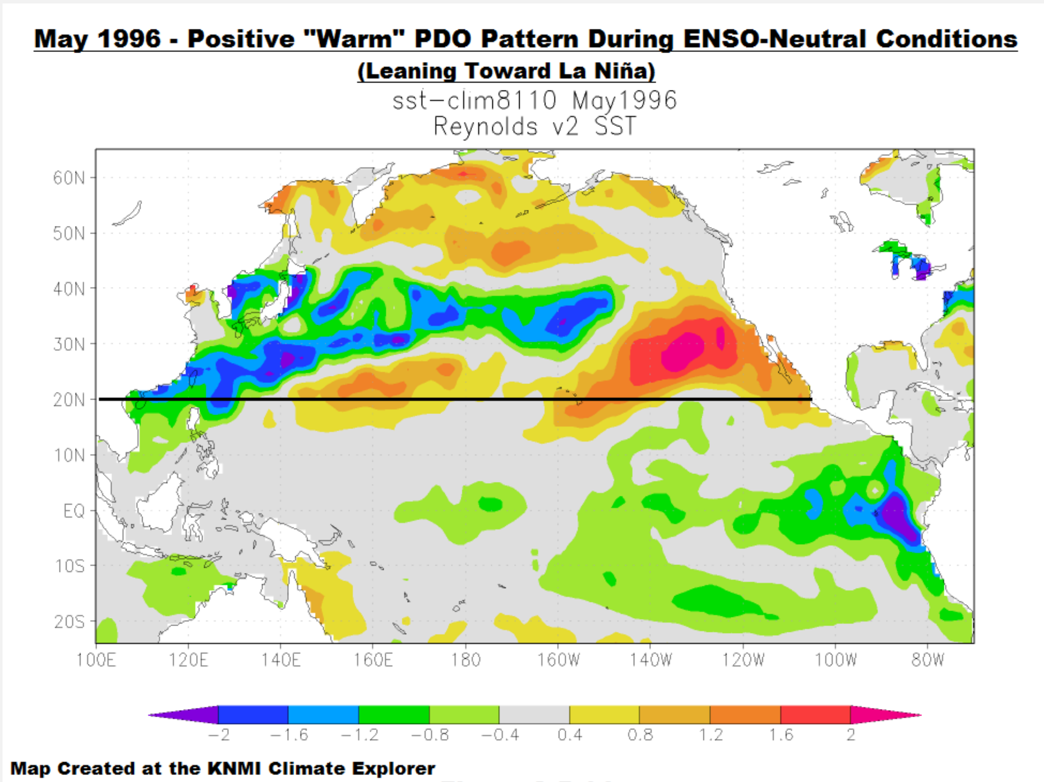


Figure 3.5-14

CONFIRMATION – THE PACIFIC DECADAL OSCILLATION INDEX DOES NOT REPRESENT THE SEA SURFACE TEMPERATURE ANOMALIES OF THE EXTRATROPICAL NORTH PACIFIC

Let’s confirm/reinforce early statements: that the Pacific Decadal Oscillation index data do not represent the sea surface temperature anomalies of the North Pacific. Figure 3.5-15 includes the sea surface temperature data for that region (20N-65N, 100E-100W). Also included in the graph is the Pacific Decadal Oscillation index data from JISAO, which have been scaled (multiplied by a factor of 0.2) to bring their variations down into line with the sea surface temperature data. You’ll also note that I’ve had EXCEL add trend lines to the graph. The trends show that sea surface temperature anomalies of the extratropical North Pacific have warmed over the past 32+ years, while the Pacific Decadal Oscillation index data show a negative trend.

Also note the monthly variations in the sea surface temperature data and the Pacific Decadal Oscillation data. They also appear to oppose one another…but not always. The Pacific Decadal Oscillation data and the sea surface temperature anomalies do have an opposing relationship but the correlation is poor. The correlation coefficient is -0.48, which is pretty bad. A correlation coefficient of -1.0 indicates a perfect negative correlation.

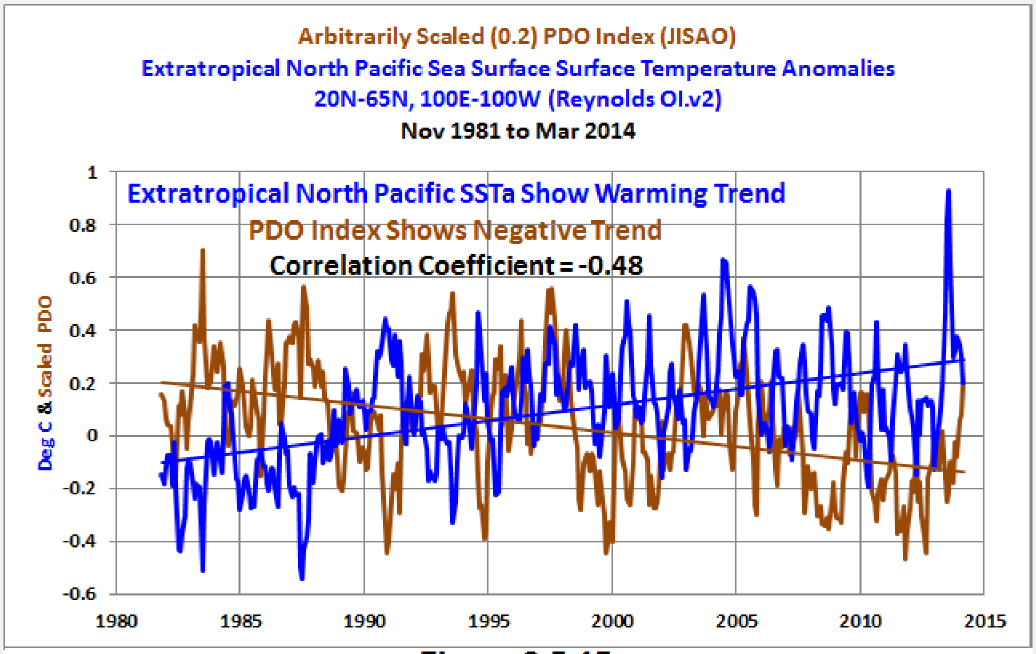


Figure 3.5-15

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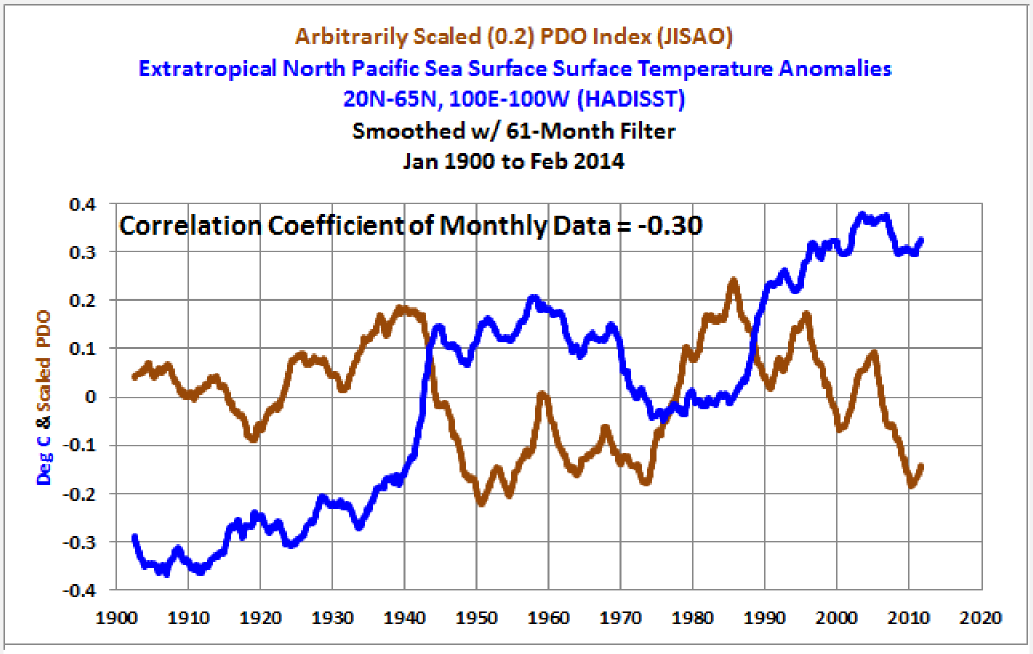

Figure 3.5-16

Figure 3.6-16 presents a similar graph, but using the long-term Pacific Decadal Oscillation index data from JISAO (January 1900 to February 2014) and the sea surface temperature anomalies of the extratropical North Pacific using the HADISST dataset. The Pacific Decadal Oscillation index data also do not represent the sea surface temperatures of the North Pacific over the long term.

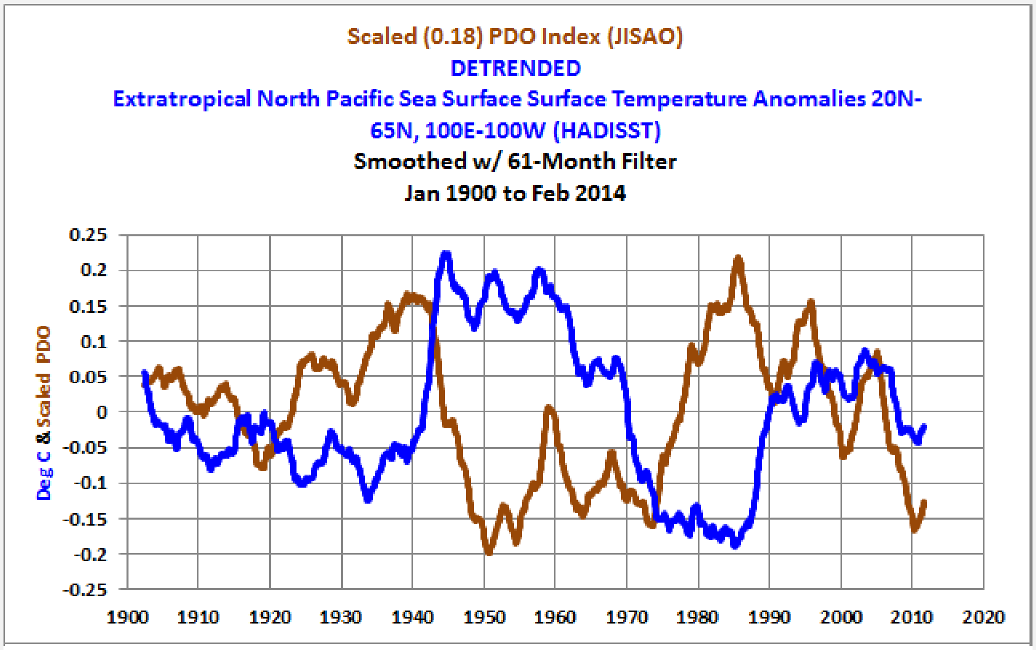

Figure 3.5-17

In Figure 3.5-17, I've detrended the sea surface temperature data and compared them to the scaled Pacific Decadal Oscillation index data. The multidecadal variations of the Pacific Decadal Oscillation index data also do not coincide with the multidecadal variations in the sea surface temperature anomalies of the North Pacific.

As noted in the heading to this discussion, the PDO index does NOT represent the sea surface temperatures of the extratropical North Pacific, the region from which it is derived.

CAN THE PACIFIC DECADAL OSCILLATION DATA BE USED TO DETERMINE THE CONTRIBUTION OF THE NORTH PACIFIC SEA SURFACE TEMPERATURES TO GLOBAL WARMING?

It's often noted, when the Pacific Decadal Oscillation is positive for multidecadal periods, global surface temperatures warm, and when the Pacific Decadal Oscillation is negative, global surface temperatures stop warming or cool a little. It's is then assumed that the Pacific Decadal Oscillation has something to do with the warming or cooling of global surface temperatures. The problem: there is no mechanism through which the Pacific Decadal Oscillation can raise or lower global surface temperatures, because the Pacific Decadal Oscillation does not represent the surface temperatures of the extratropical North Pacific (where the Pacific Decadal Oscillation is derived).

Figure 3.5-18 compares the sea surface temperature anomalies of the extratropical North Pacific with global sea surface temperature anomalies. The UKMO HADISST data are being presented. And the data have been smoothed with 61-month filters to help show the differences in the long-term variations. There are periods when the sea surface temperatures of the extratropical North Pacific run in parallel with the global surface temperature data. At those times, the sea surface temperatures are not adding to or suppressing the variations in the global data. There are periods when the sea surface temperatures of the extratropical North Pacific warm faster than the global data. At those times, the sea surface temperatures of the North Pacific (north of 20N) are adding to the warming of global sea surface temperatures. And, conversely, the sea surface temperatures of the extratropical North Pacific are suppressing the warming of global data when they are warming at a slower rate than the global data…and adding to the cooling when the surface of the North Pacific is cooling faster than they are globally.

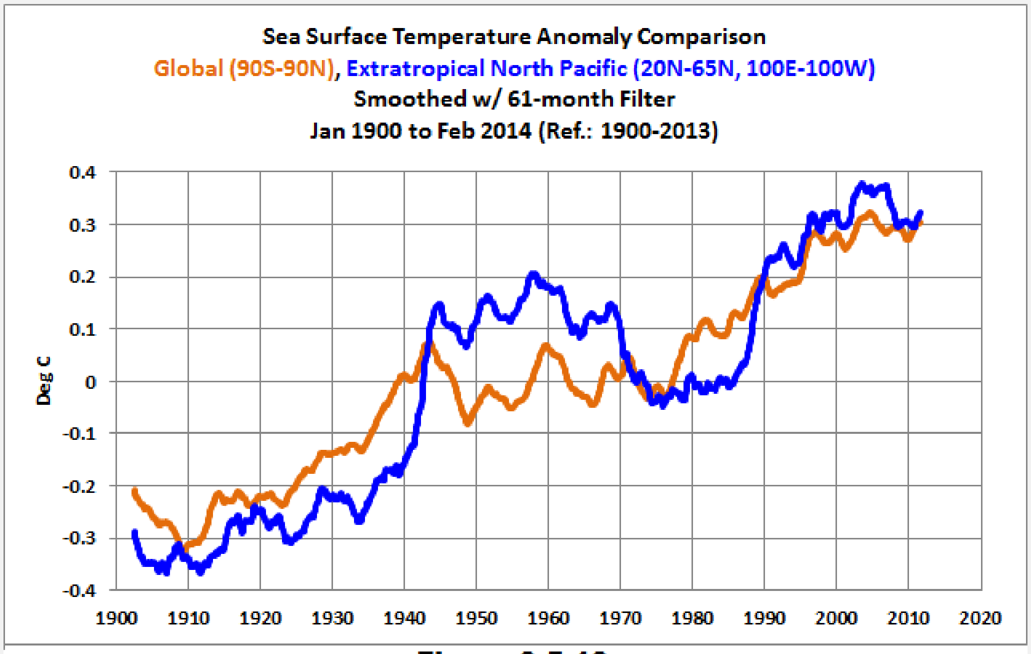

Figure 3.5-18

Let's subtract the global sea surface temperature data from the data for the extratropical North Pacific. We'll call that difference the "Extratropical North Pacific Residual". See Figure 3.5-19. The "Extratropical North Pacific Residual" illustrates the additional variations of the sea surface temperatures of the North Pacific (north of 20N) above and beyond the global sea surface temperatures. Also included in Figure 3.5-19 is the scaled Pacific Decadal Oscillation index. Both datasets have once again been smoothed with 61-month filters. It's very obvious that the Pacific Decadal Oscillation data do not represent the additional variability of the North Pacific sea surface temperatures. In fact, over multidecadal timeframes, the Pacific Decadal Oscillation data can be inversely related to the extra variability of the sea surface temperatures of the extratropical North Pacific.

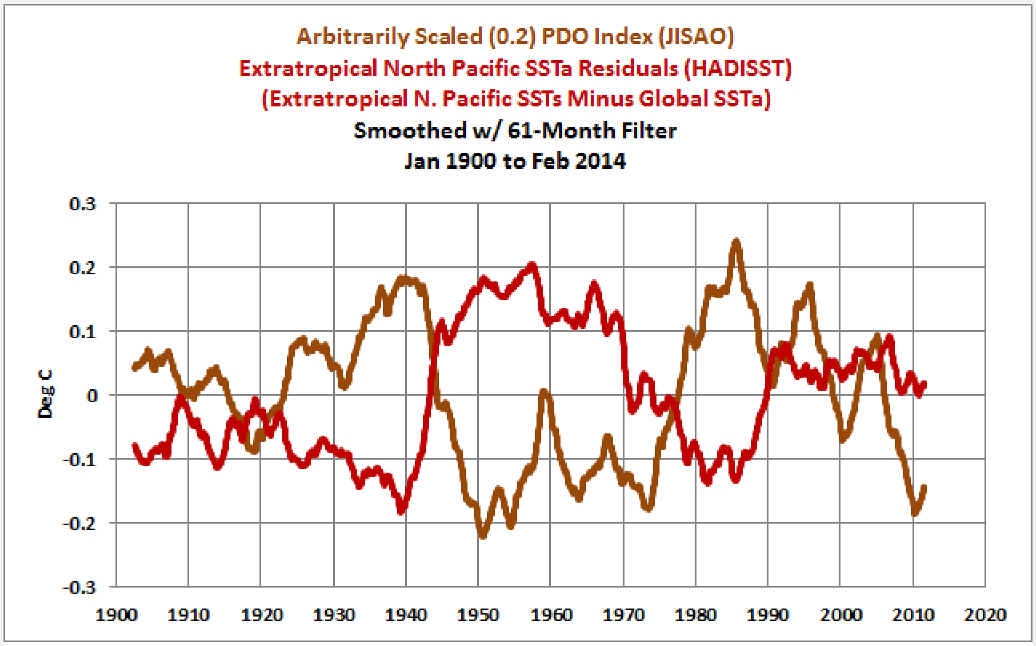

Figure 3.5-19

There's another way to illustrate the inverse relationship between the Pacific Decadal Oscillation and surface temperatures, and that's with maps that show the correlation of Northern Hemisphere surface temperatures with the Pacific Decadal Oscillation and the correlation of the Northern Hemisphere surface temperatures with the sea surface temperatures of the extratropical North Pacific. See Figure 3.5-20. The top map shows that surface temperatures of most of the Northern Hemisphere are negatively correlated with the Pacific Decadal Oscillation index. That negative correlation means that when the Pacific Decadal Oscillation data increases, the surface temperatures for most of the Northern Hemisphere show cooling. On the other hand, the surface temperatures for most of the Northern Hemisphere are positively correlated with the sea surface temperatures of the extratropical North Pacific. See the bottom map of Figure 3.5-20. That is, the surface temperatures for much of the Northern Hemisphere warm when the surface of the extratropical North Pacific warms, and it cools when the surface of the extratropical North Pacific cools.

So the answer to the question posed in the heading for this section is no. The Pacific Decadal Oscillation data cannot be used to determine the contribution of the North Pacific sea surface temperatures to global warming. The Pacific Decadal Oscillation data do not represent the sea surface temperatures of the extratropical North Pacific.

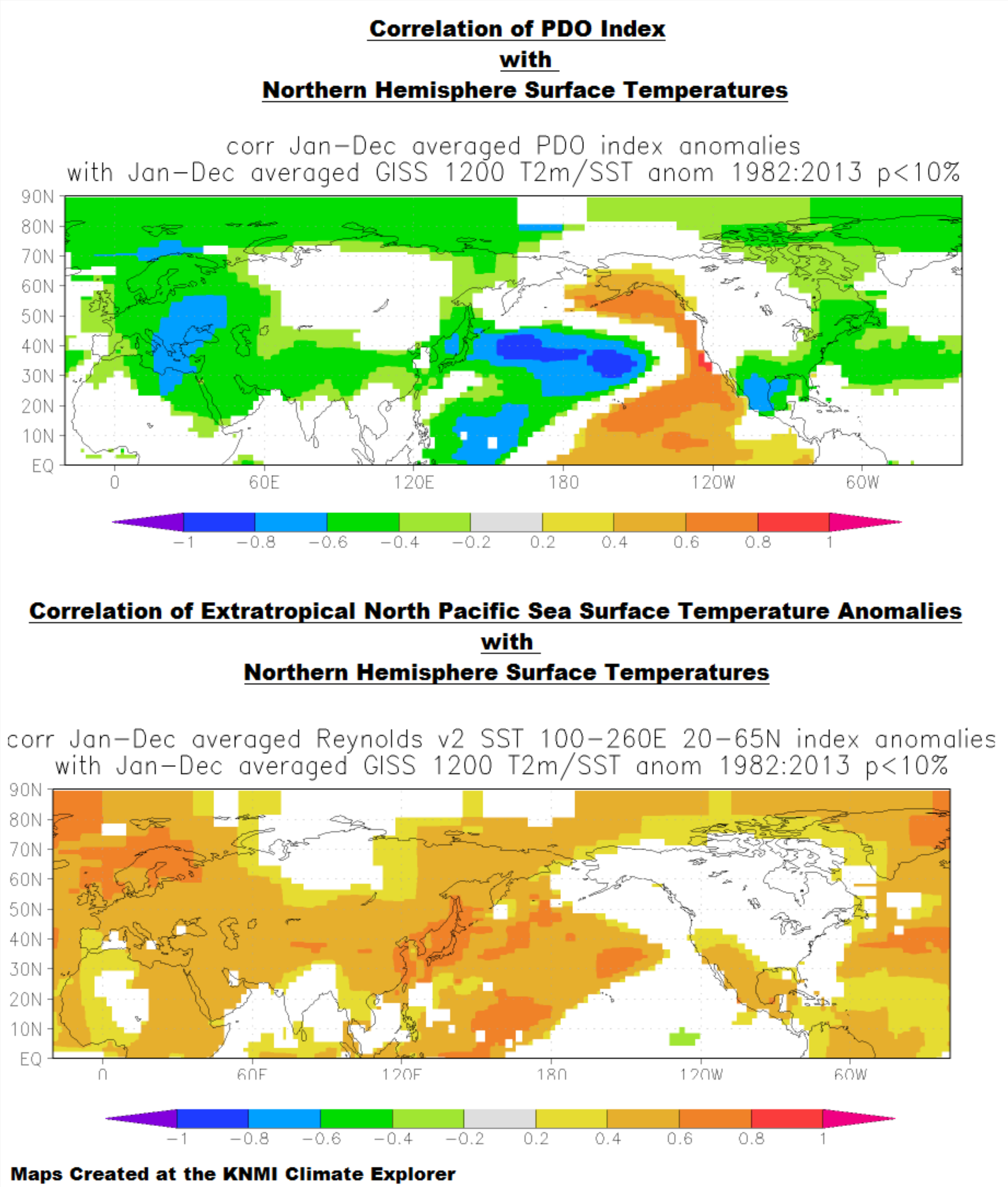

Figure 3.5-20

Note: If you were to scroll back up to the previous chapter, you'd find a correlation map (top map in Figure 3.4-15) similar to the bottom half of Figure 3.5-20. And you'll notice that the correlations are not the same. The bottom half of Figure 3.5-20 shows the correlations of the Northern Hemisphere surface temperatures with the <u>extratropical</u>

North Pacific (20N-65N) sea surface temperature data for the period of 1982 to 2013, while the top cell of Figure 3.4-15, shows the correlations for the entire North Pacific (0-65N). Different latitudes of the North Pacific have different correlations with the surface temperature of the Northern Hemisphere. The primary reason: El Niño and La Niña events impact surface temperatures globally, but there is no direct El Niño and La Niña component in the extratropical (20N-65N) data, just aftereffects, while El Niño and La Niña events do directly impact the data for the entire North Pacific (0-65N).

[End note.]

THE EASTERN OR WEST-CENTRAL PORTIONS OF THE NORTH PACIFIC: WHICH AGREES BEST WITH THE PACIFIC DECADAL OSCILLATION INDEX?

Earlier we discussed how a "warm" or "cool" Pacific Decadal Oscillation index value appears to be tied to the sea surface temperature anomalies of the eastern extratropical North Pacific. That is, sea surface temperatures in the eastern extratropical North Pacific tend to be elevated when the Pacific Decadal Oscillation is "warm", and depressed when the Pacific Decadal Oscillation is "cool". And we discussed how the west-central portion of the extratropical North Pacific is "cool" when the Pacific Decadal Oscillation is "warm" and, conversely, the west-central portion is "warm" when the Pacific Decadal Oscillation is "cool".

But, in terms of sea surface temperature anomalies, which of those two regions agrees better with the Pacific Decadal Oscillation index data: the eastern or the west-central? The use of the terms "warm" and "cool" draws our attention to the eastern extratropical North Pacific, but do the sea surface temperatures there actually correlate well with the Pacific Decadal Oscillation?

To determine this, we'll present the satellite era sea surface temperature data for those two portions of the extratropical North Pacific, and compare them to the Pacific Decadal Oscillation index. See the map in Figure 3.5-21. For this part of the discussion, we'll call the west-central portion by the name that's commonly used for that region: the Kuroshio-Oyashio Extension (KOE). (I've tipped my hand with the notes on the illustration.) This discussion is also similar to one we had in the last chapter about the North Pacific sea surface temperatures, but here, we're using different coordinates to reflect the region represented by the Pacific Decadal Oscillation data.

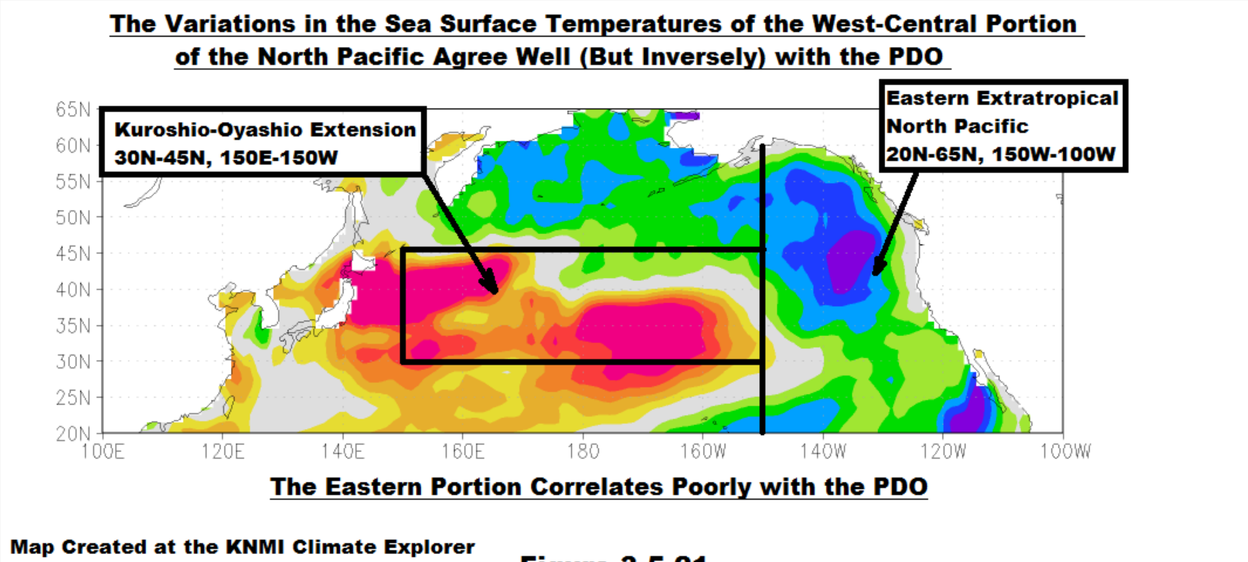

Figure 3.5-21

# # #

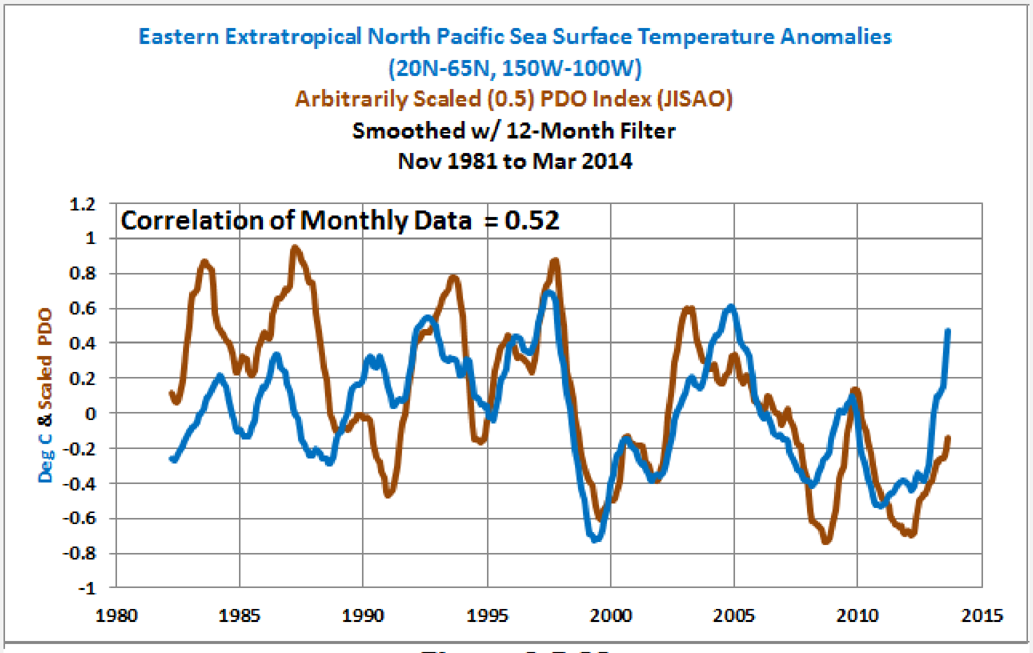

Figure 3.5-22

Let's start with the eastern region. Figure 3.5-22 presents the sea surface temperature anomalies of the eastern extratropical North Pacific (20N-65N, 150W-100W). Also shown is the Pacific Decadal Oscillation index that has been arbitrarily scaled (scaling factor = 0.5). After the 1997/98 El Niño, the variations in the Pacific Decadal Oscillation and in the sea surface temperatures of the eastern region of the North Pacific (north of 20N) tend to agree with one another, but before that El Niño, there is little agreement.

Overall, the two datasets correlate quite poorly since November 1981, with a correlation coefficient of 0.52.

The scaled Pacific Decadal Oscillation index is compared to the sea surface temperature anomalies of the Kuroshio-Oyashio Extension (west-central portion of extratropical North Pacific) in Figure 3.5-23. If not for that three-year stretch from 2004 through 2006, the variations in the Pacific Decadal Oscillation data would mirror the variations in the sea surface temperatures of the Kuroshio-Oyashio Extension. The correlation coefficient of those two datasets is -0.91, which is much better than the eastern region, except that it's inverted.

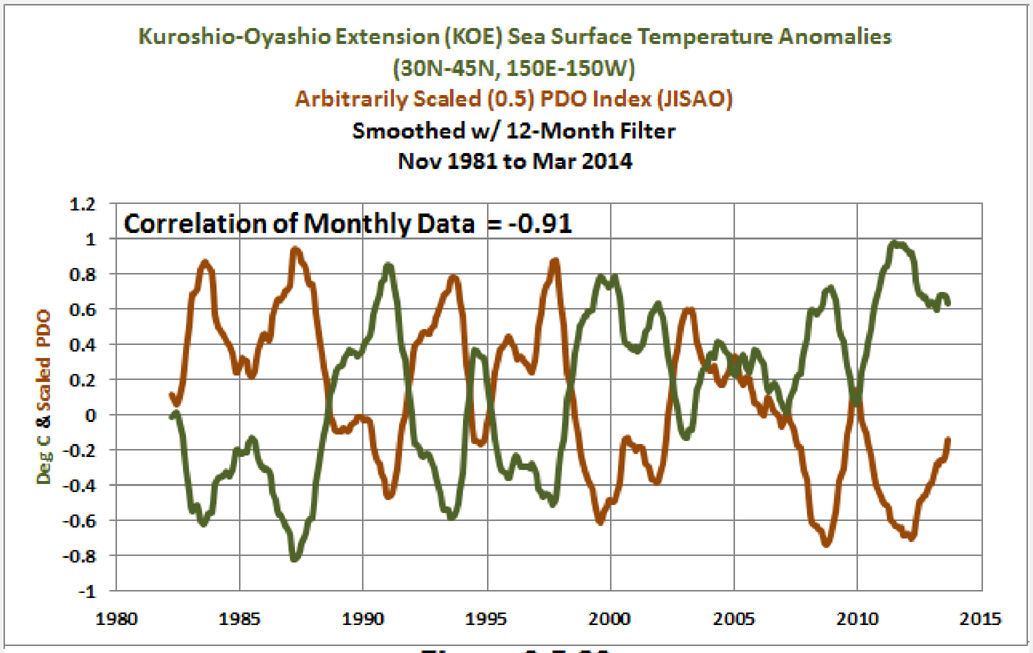

Figure 3.5-23

That suggests that studies of the variability of the Pacific Decadal Oscillation during the satellite era and the relationship of the Pacific Decadal Oscillation with ENSO are, for the most part, studies of the variations in the sea surface temperatures of the Kuroshio-Oyashio Extension, but with the results inverted for the Pacific Decadal Oscillation. Or to phrase it differently, studies of the variability of the Pacific Decadal Oscillation are, for the most part, not studies of the eastern extratropical North Pacific.

THREE PACIFIC DECADAL OSCILLATION INDICES ARE AVAILABLE THROUGH THE KNMI CLIMATE EXPLORER

The Pacific Decadal Oscillation index maintained by JISAO is the traditional Pacific Decadal Oscillation index. It's used most often in climate-related studies. But the JISAO Pacific Decadal Oscillation index is derived from three sea surface temperature datasets, two of which are obsolete. The Pacific Decadal Oscillation data from JISAO are calculated from an obsolete version of the UKMO sea surface temperature data from January 1900 to December 1981 and from an obsolete version of the Reynolds optimum interpolation sea surface temperature data from January 1982 through December 2001. JISAO uses the up-to-date Reynolds OI.v2 sea surface temperature data since January 2002. So the JISAO Pacific Decadal Oscillation data are a mix of very different sea surface temperature datasets. See the JISAO PDO data webpage here for confirmation.

The Monthly climate indices webpage at the KNMI Climate Explorer includes 3 Pacific Decadal Oscillation datasets: the JISAO data, and Pacific Decadal Oscillation data based on two other sea surface temperature datasets: NOAA's ERSST.v3b data and UKMO's HADSST3 data.

- Pacific Decadal Oscillation (1900-now, Mantua, U. Washington), which is the JISAO Pacific Decadal Oscillation data,
- Pacific Decadal Oscillation based on ERSST.v3b (1880-now), and
- Pacific Decadal Oscillation based on HadSST3 (1850-now).

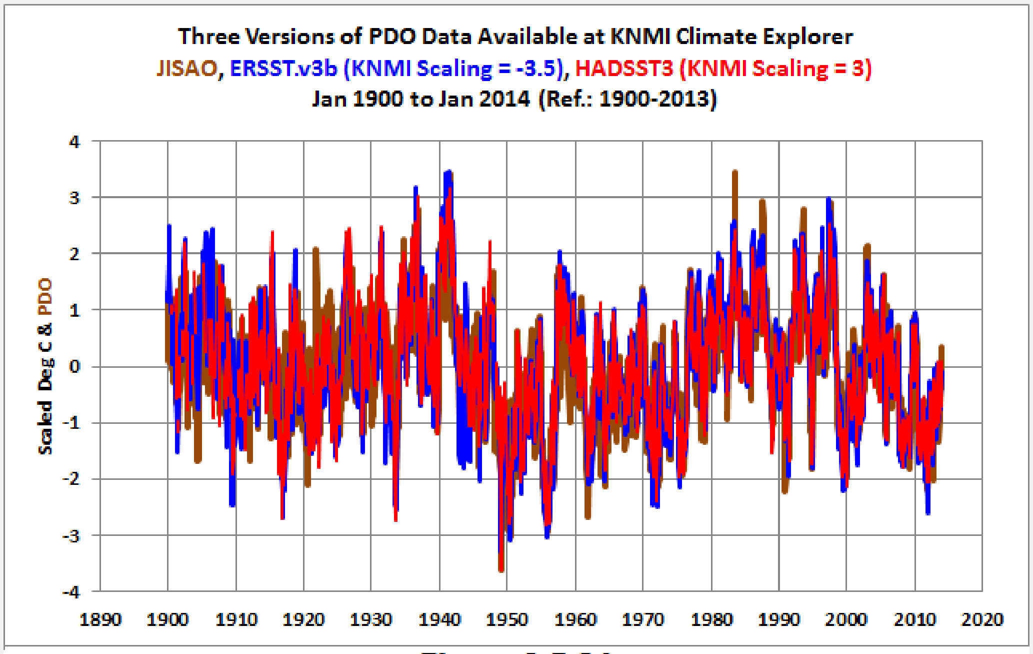

Figure 3.5-24

Looking at the three Pacific Decadal Oscillation datasets in monthly form, Figure 3.5-24, the three datasets appear to agree reasonably well. In fact, the ERSST.v3b and HADSST3 data correlate well with one another (correlation coefficient of 0.94). But the correlations are lower between the JISAO Pacific Decadal Oscillation index data and the other two datasets (JISAO Pacific Decadal Oscillation correlation coefficients: 0.85 with ERSST.v3b data and 0.86 with HADSST3 data). With that in mind, if you were studying the Pacific Decadal Oscillation in close relation to a specific surface temperature dataset, it might be best to use the Pacific Decadal Oscillation index data associated with the surface temperature data being studied.

Figure 3.5-25 presents the three Pacific Decadal Oscillation datasets smoothed with 121-month running-mean filters. They agree better in some periods than in others. The temporary upswing in the JISAO Pacific Decadal Oscillation data from the mid-1950s to about 1970 is not as great as the other two datasets. And the JISAO Pacific Decadal Oscillation does not dip as low as the other two in the early part of the 20th century.

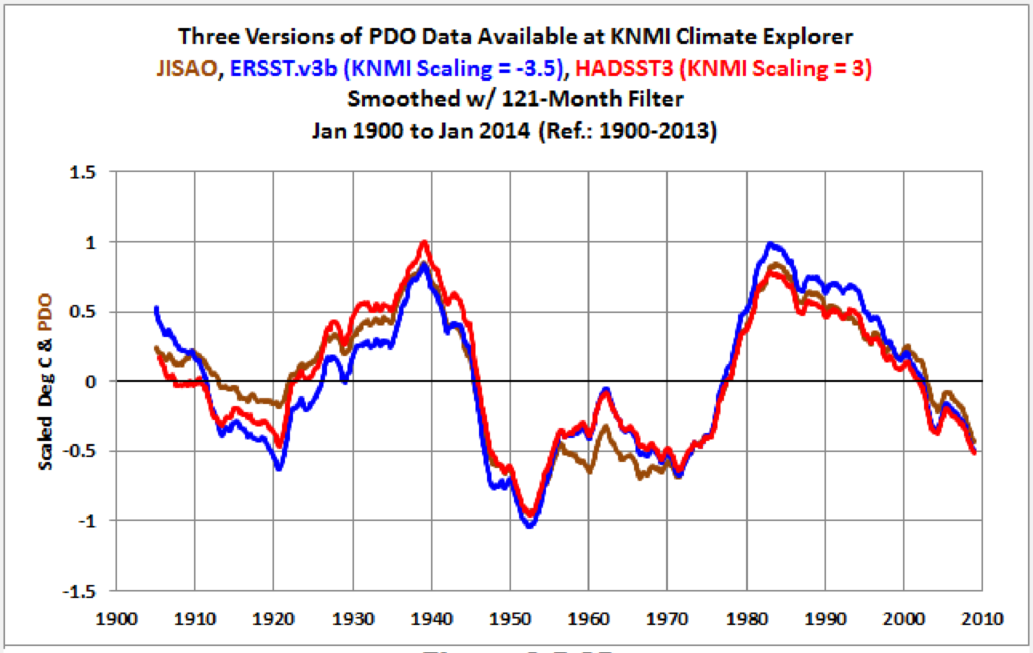

Figure 3.5-25

A couple of things to note about Figures 3.5-24 and 3.5-25: On the data pages at the KNMI Climate Explorer for the ERSST.v3b- and HADSST3-based Pacific Decadal Oscillation data, KNMI lists the scaling factors applied to those datasets. For the ERSST.v3b-based Pacific Decadal Oscillation data, the scaling factor was -3.5, and the HADSST3-based Pacific Decadal Oscillation data was scaled by a factor of 3.0. I suspect the scaling factors are based on the standard deviations of both datasets…and that they have been rounded.

Note also that the ERSST.v3b data were scaled by a factor of -3.5. This indicates the ERSST.v3b-based Pacific Decadal Oscillation data were originally inverted…that is, they were the opposite sign of how the Pacific Decadal Oscillation data is normally presented. KNMI then multiplied the ERSST.v3b Pacific Decadal Oscillation data by a negative number in order to present them as we're used to seeing them.

With the scaling factors, assuming the values are rounded, we can get a rough estimate of the actual variations of the Pacific Decadal Oscillation data in terms of sea surface temperatures in deg C.

THE PACIFIC DECADAL OSCILLATION DATA IN DEG C

When I first began to study ocean processes, I believed (wrongly) that the Pacific Decadal Oscillation were El Niño-like and La Niña-like events taking place in the North Pacific. One of the influences on my initial misunderstanding was how the Pacific Decadal Oscillation data were presented. Overlooking the fact that I didn't know how much the standardization exaggerated the Pacific Decadal Oscillation index, the graphs of the raw Pacific Decadal Oscillation data showed monthly variations in excess of -2.0 to +3.0, which were comparable to, if not larger than, the variations in the sea surface temperature anomalies of the equatorial Pacific. See Figure 3.5-26. The standardization of the JISAO Pacific Decadal Oscillation data may also have greatly exaggerated the importance of the Pacific Decadal Oscillation for other people. Hopefully, this presentation will put an end to that.

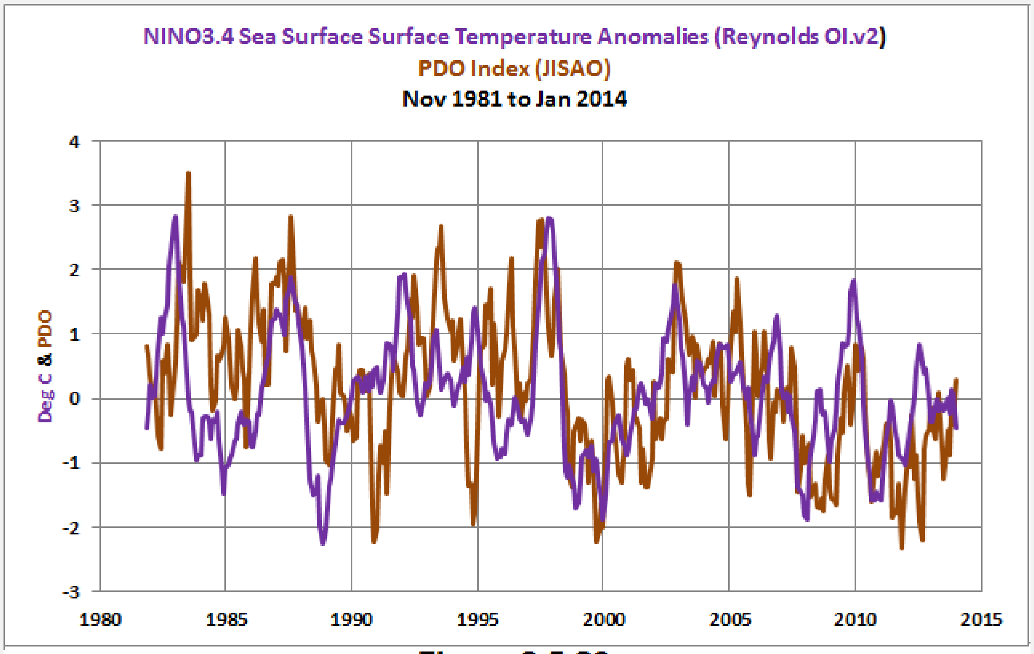

Figure 3.5-26

So let's look at the magnitudes of the variations of the HADSST3 and ERSST.v3b Pacific Decadal Oscillation indices in terms of deg C. To accomplish this, we'll simply divide those Pacific Decadal Oscillation indices by the scaling factors listed by KNMI, leaving the ERSST.v3b Pacific Decadal Oscillation data inverted…and keeping in mind that the listed scaling factors were likely rounded. So we're looking at rough approximations of the two Pacific Decadal Oscillation datasets in degrees C. In Figure 3.5-27, the results are compared to NINO3.4 sea surface temperature anomalies, our

ENSO (El Niño and La Niña) index, as a reference. The sea surface temperature-based ENSO signal dwarfs the variations of the two Pacific Decadal Oscillation datasets.

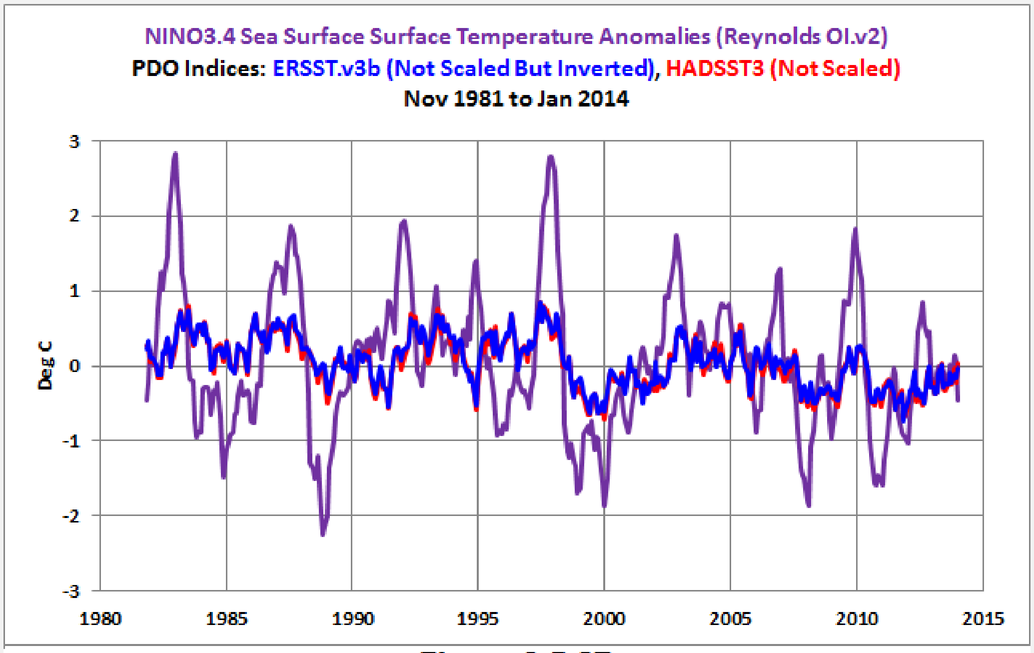

Figure 3.5-27

That's not to say that the sea surface temperatures of the North Pacific are not important. As we discussed in Chapter 3.4 – Ocean Mode: North Pacific Multidecadal Variability, the multidecadal variations in the sea surface temperature anomalies there can enhance or suppress the warming of global sea surface temperatures. But, again, the Pacific Decadal Oscillation index data do not represent the sea surface temperatures of the North Pacific.

COMBINED EFFECTS OF ENSO AND PDO ON PRECIPITATION AROUND THE GLOBE

A 2014 paper by Wang et al. sheds new light on the combined effects of ENSO and the Pacific Decadal Oscillation on precipitation (or lack thereof) around the globe. The paper is logically titled Combined effects of the Pacific Decadal Oscillation and El Niño-Southern Oscillation on Global Land Dry–Wet Changes. The abstract reads:

> *The effects of natural variability, especially El Niño-Southern Oscillation (ENSO) effects, have been the focus of several recent studies on the change of drought patterns with climate change. The interannual relationship between ENSO and the global climate is not stationary and can be modulated by the Pacific Decadal Oscillation (PDO). However, the global land distribution of the dry–wet changes associated with the combination of ENSO and the PDO remains unclear. In the*

> *present study, this is investigated using a revised Palmer Drought Severity Index dataset (sc_PDSI_pm). We find that the effect of ENSO on dry–wet changes varies with the PDO phase. When in phase with the PDO, ENSO-induced dry–wet changes are magnified with respect to the canonical pattern. When out of phase, these dry–wet variations weaken or even disappear. This remarkable contrast in ENSO's influence between the two phases of the PDO highlights exciting new avenues for obtaining improved global climate predictions. In recent decades, the PDO has turned negative with more La Niña events, implying more rain and flooding over land. La Niña-induced wet areas become wetter and the dry areas become drier and smaller due to the effects of the cold PDO phase.*

That agrees with our understandings of ENSO and the Pacific Decadal Oscillation. If the wind and sea level pressure patterns in the North Pacific are such that an El Niño-like spatial pattern exists in the sea surface temperatures there without an El Niño, then when an El Niño event does occur (ENSO and PDO are in phase), its effects on precipitation are magnified, and when a La Niña event occurs against an El Niño-like background (ENSO and PDO out of phase), then the impacts of ENSO on precipitation are suppressed. Conversely, if a La Niña-like spatial pattern exists in the sea surface temperatures there without a La Niña, then when a La Niña does occur (ENSO and PDO in phase), its effects are also magnified, and when an El Niño event occurs against a La Niña-like background (ENSO and PDO out of phase), then the impacts of the El Niño on precipitation are suppressed.

THERE ARE AT LEAST TWO YEARS BEING USED FOR THE RECENT SWITCH FROM WARM TO COOL PHASES OF THE PDO

Another note about Wang et al. (2014), and it has to do with the timing of the recent shift from the warm to cool phase of the PDO. See the Wang et al. (2014) Table 1: Classification of years based on the phases of ENSO and the PDO for the period of 1900–2012. The year of 1900, for example, refers to the boreal 1900/1901 winter. Note how the 1998-01 La Niña and the 2002/03 El Niño are considered to have occurred in the warm phase and that the first ENSO event in the recent cold phase is the 2004/05 El Niño. That indicates, according to Wang et al., the switch of the Pacific Decadal Oscillation from warm to cool phase happened in 2003/04. Other papers say the switch occurred in 1999. See Trenberth and Fasullo (2013) An apparent hiatus in global warming?

It’s curious how the climate science community can’t agree on something as simple as the timing of the recent switch of the Pacific Decadal Oscillation from warm to cool phases.

CLIMATE MODELS DO NOT SIMULATE THE PACIFIC DECADAL OSCILLATION

Once again, we simply have to refer to the 2007 blog post written by Dr. Kevin Trenberth Predictions of Climate at Nature.com's blog ClimateFeedback. Dr. Trenberth wrote (my boldface):

> *None of the models used by IPCC are initialized to the observed state and none of the climate states in the models correspond even remotely to the current observed climate. In particular, the state of the oceans, sea ice, and soil moisture has no relationship to the observed state at any recent time in any of the IPCC models.* ***There is neither an El Niño sequence nor any Pacific Decadal Oscillation that replicates the recent past; yet these are critical modes of variability that affect Pacific rim countries and beyond.*** *The Atlantic Multidecadal Oscillation, that may depend on the thermohaline circulation and thus ocean currents in the Atlantic, is not set up to match today's state, but it is a critical component of the Atlantic hurricanes and it undoubtedly affects forecasts for the next decade from Brazil to Europe. Moreover, the starting climate state in several of the models may depart significantly from the real climate owing to model errors. I postulate that regional climate change is impossible to deal with properly unless the models are initialized.*

The Pacific Decadal Oscillation was first "discovered" in the late 1990s and the impacts of the Pacific Decadal Oscillation on North American precipitation patterns were identified not long after that. Yet the climate models used by the IPCC for their 5th Assessment Report in 2013 were not able to simulate the Pacific Decadal Oscillation. Let's return to the 2013 paper by Ruiz-Barradas, et al.: "The Atlantic Multidecadal Oscillation in Twentieth Century Climate Simulations: Uneven Progress from CMIP3 to CMIP5." The full paper is here. In their "Concluding Remarks" they explain why it's important for climate models to be able to accurately simulate the Pacific Decadal Oscillation, a.k.a. PDO:

> *If climate models do not incorporate the mechanisms associated to the generation of the AMO (or any other source of decadal variability like the PDO) and in turn incorporate or enhance variability at other frequencies, then the models ability to simulate and predict at decadal time scales will be compromised and so the way they transmit this variability to the surface climate affecting human societies.*

THE PACIFIC DECADAL OSCILLATION IS NOT A FORCED COMPONENT OF CLIMATE MODELS

I'm going to borrow an illustration for this discussion from my October 2013 blog post Questions the Media Should Be Asking the IPCC – The Hiatus in Warming. There it was presented as Figure 5. The data and models end 2 years ago but that has no impact on this presentation.

As you'll recall from our discussion of Figure 3.25-23, the variations in the sea surface temperature anomalies of the Kuroshio-Oyashio Extension (30N-45N, 150E-150W) correlate remarkably well (for two climate-related indices) with the Pacific Decadal Oscillation index, with a correlation coefficient of -0.91. But the relationship is inverted. So, we can use the sea surface temperature anomalies of the Kuroshio-Oyashio Extension as a proxy for the Pacific Decadal Oscillation index.

For the following model-data comparison, I'm altering the data and model outputs a little more by subtracting the modeled and observed global sea surface temperature anomalies from their respective sea surface temperature anomalies of the Kuroshio-Oyashio Extension. See Figure 3.5-28. The model outputs and data stretch from 1870 to 2013 and both have been smoothed with 121-month filters to highlight their multidecadal variations. As usual, we're illustrating the model mean of the climate models stored in the CMIP5 archive, because the model mean represents the forced component of the models. And for this comparison, we're using HADISST data from the UK Met Office.

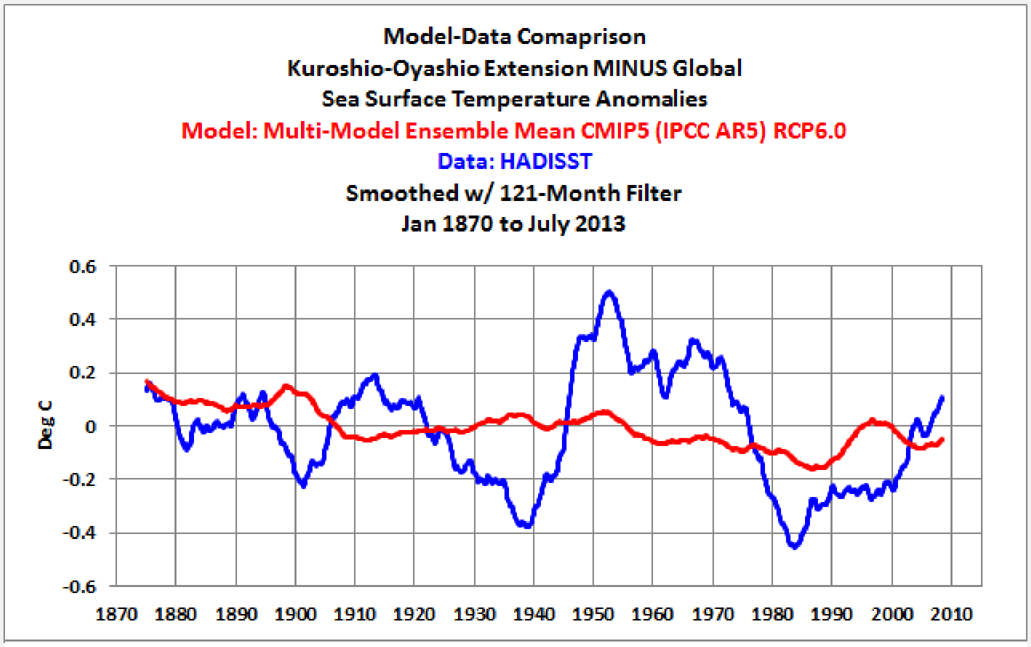

Figure 3.5-28

As shown with the blue curve in Figure 3.5-28, there are very large multidecadal variations in the sea surface temperatures of the Kuroshio-Oyashio Extension after the global data have been subtracted. On the other hand, using the models prepared for the IPCC's 5th Assessment Report, we get totally different results when we subtract the modeled global sea surface temperatures from the modeled sea surface temperatures of the Kuroshio-Oyashio Extension. (See the red curve in Figure 3.5-28.) The models show very little additional variability in the sea surface temperatures Kuroshio-Oyashio Extension, above and beyond the global sea surface temperature data. Because the model mean represents the forced component of the climate models, this means that the additional variations in the sea surface temperatures of the Kuroshio-Oyashio Extension are not driven by the greenhouse gases that are used to force the climate models.

Phrased another way, because the sea surface temperatures of the Kuroshio-Oyashio Extension can be used as a proxy for the Pacific Decadal Oscillation, it is safe to say that the Pacific Decadal Oscillation occurs naturally, that the PDO is not forced by the man-made greenhouse gases that are used to drive the models.

CHAPTER SUMMARY

Hopefully this chapter cleared up some misunderstandings about the Pacific Decadal Oscillation and will help you to be able to sort through much of the misinformation that exists about it. The key points:

- The Pacific Decadal Oscillation index does not represent the sea surface temperature anomalies of the extratropical North Pacific or the North Pacific or the Pacific Ocean in general.
- The Pacific Decadal Oscillation index represents the spatial pattern of the sea surface temperature anomalies of the extratropical North Pacific (20N-65N).
- The Pacific Decadal Oscillation index is not an ENSO (El Niño-La Niña) index, but it does reflect the impact that El Niño and La Niña events have on the spatial patterns of the sea surface temperature anomalies of the extratropical North Pacific.
- The Pacific Decadal Oscillation index is also impacted by the wind patterns (and related sea level pressures) in the extratropical North Pacific, which is why the Pacific Decadal Oscillation index has different multidecadal variations than those of El Niño and La Niña events.
- The dominant region of the extratropical North Pacific is the west-central portion, not the eastern portion, but the west-central portion is inversely related to the Pacific Decadal Oscillation index.
- The Pacific Decadal Oscillation index data have been standardized (divided by the standard deviation), and the standardization greatly exaggerates the importance of the Pacific Decadal Oscillation.

3.6 – Ocean Mode: Interdecadal Pacific Oscillation

INITIAL NOTE: Many of the illustrations in this chapter were taken from my May 2013 blog post Meehl et al (2013) Are Also Looking for Trenberth's Missing Heat. Those graphs may end in 2013, but that has no impact on this discussion because we're examining multidecadal variations, not what's happened recently.

# # #

The Interdecadal Pacific Oscillation is a seldom-used dataset derived from the sea surface temperature data of the entire Pacific Ocean. Like the Pacific Decadal Oscillation Index data, the Interdecadal Pacific Oscillation data are based on sea surface temperature data, but they do not represent the sea surface temperatures of the Pacific Ocean. In other words, the Interdecadal Pacific Oscillation is an abstract form of sea surface temperature data from the Pacific. The Interdecadal Pacific Oscillation represents the El Niño- and La Niña-like spatial patterns in the entire Pacific Ocean.

The Interdecadal Pacific Oscillation was defined and the method for calculating it was first presented in the 1999 paper by Power et al. Inter-decadal Modulation of the Impact of ENSO on Australia. In that paper, Power et al. were using the Interdecadal Pacific Oscillation to explain why El Niño and La Niña events had certain impacts on Australian weather in some time periods and different impacts during others.

The Interdecadal Pacific Oscillation has reappeared in scientific studies in recent years. Some climate scientists are using the Interdecadal Pacific Oscillation in papers that had tried to explain the slowdown in the warming of global surface temperatures. One such paper was Meehl et al. (2013) Externally forced and internally generated decadal climate variability associated with the Interdecadal Pacific Oscillation. A preprint copy of Meehl et al (2013) is here. Meehl et al (2013) is an update of Meehl et al (2011) Model-based evidence of deep-ocean heat uptake during surface-temperature hiatus periods. Meehl et al. (2013) was receiving attention around the blogosphere, so I responded to the talking points, along with a detailed explanation of the Interdecadal Pacific Oscillation, in the blog post Meehl et al (2013) Are Also Looking for Trenberth's Missing Heat. I've rewritten a part of that post for this chapter, using many of the same illustrations.

The papers such as Meehl et al. (2013) are using the Interdecadal Pacific Oscillation data to define periods when El Niño events dominated and when La Niña events were dominant. The reason: they're blaming the slowdown and stoppage in global warming on the recent dominance of La Niña events. Curiously, they don't bother to mention, if a dominance of La Niña events can stop the warming, then a dominance of El Niño events would contribute to the warming, as was experienced during the warming period from the mid-1970s to the turn of the century.

OVERVIEW OF THE INTERDECADAL PACIFIC OSCILLATION

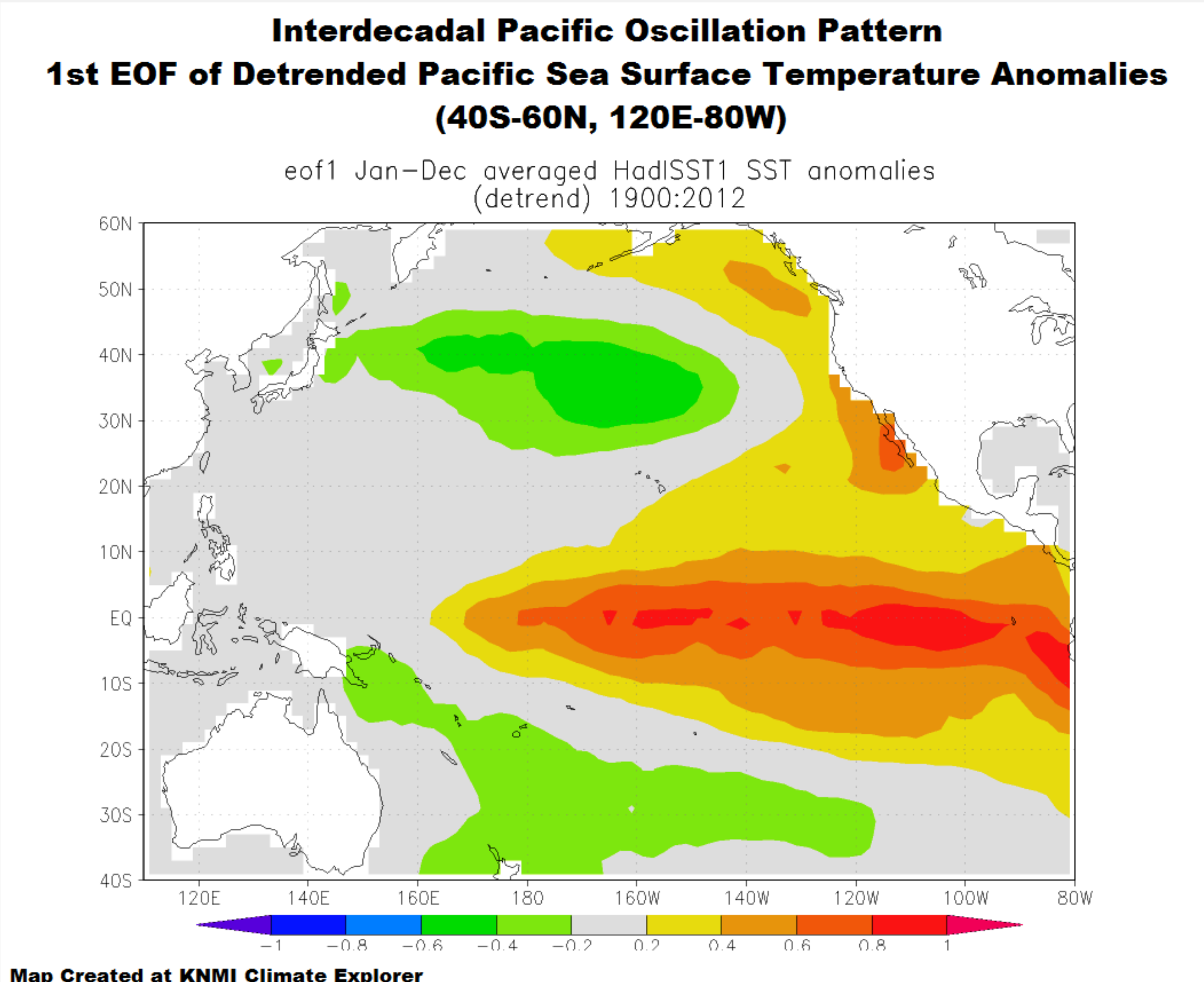

Figure 3.6-1

As noted above, like the Pacific Decadal Oscillation dataset, the Interdecadal Pacific Oscillation (IPO) data are an abstract form of the sea surface temperature data from the Pacific Ocean.   Seemingly, there are as many definitions of the Interdecadal Pacific Oscillation as there are papers about it. Since this chapter is based on Meehl et al (2013), we'll use the latitudes they presented for the Interdecadal Pacific Oscillation in their Figure 5, which were 40S-60N, and use the longitudes of 120E-80W to minimize the influence of other ocean basins. See Figure 3.6-1. Afterwards I'll compare the "official" Interdecadal Pacific Oscillation index data to the Interdecadal Pacific Oscillation data I've created.   There's little difference in the timing of the changes from positive to negative Interdecadal Pacific Oscillation modes as you shall see.

The Pacific Decadal Oscillation data is derived from the sea surface temperatures of the extratropical North Pacific, but the Interdecadal Pacific Oscillation is determined from the data for most of the Pacific basin (40S-60N, 120E-80W). In the Pacific Decadal Oscillation data, global surface sea temperatures are subtracted from the North Pacific data. That does not make sense for an examination of Pacific data because the Pacific represents so much of the global ocean data. So for this presentation, I've simply detrended the Pacific data…before the statistical analysis.

Empirical Orthogonal Function (EOF) and Principal Component Analysis are used to determine the dominant spatial pattern in the Pacific sea surface temperature anomalies. That is, for this discussion, the Interdecadal Pacific Oscillation data represents how closely spatial pattern of the sea surface temperature anomalies at any given time in the Pacific basin resemble the dominant spatial pattern of the sea surface temperature anomalies there. Refer again to Figure 3.6-1. The map was created at the KNMI Climate Explorer. It uses HADISST data for the Empirical Orthogonal Analysis and is based on the period of 1900 to 2012.

Because El Niño and La Niña events are the dominant mode of natural variability in the Pacific (and the globe), the Interdecadal Pacific Oscillation basically presents an East Pacific El Niño-caused spatial pattern, as shown above in Figure 3.6-1. That is, during a typical East Pacific El Niño, the sea surface temperatures warm in the central and eastern tropical Pacific, and there is warming of the sea surface temperatures along the west coast of North America, but to a lesser extent. Changes in atmospheric and ocean circulation during an El Niño cause the sea surface temperatures to cool east of Japan (the region called the Kuroshio-Oyashio Extension or KOE) and east of Australia. The cool (green) portion of the South Pacific east of Australia stretching southeastward is the location of the South Pacific Convergence Zone (SPCZ).

Let's reinforce that discussion. Like the Pacific Decadal Oscillation data, the data for the Interdecadal Pacific Oscillation is determined by the data analysis portion of Empirical Orthogonal Analysis, and that data analysis is called Principal Component Analysis. The Interdecadal Pacific Oscillation data represent how closely the spatial pattern in the Pacific at a given time portrays (resembles) the El Niño-like spatial pattern. Positive Interdecadal Pacific Oscillation data values indicate an El Niño-like pattern, and conversely, a negative Interdecadal Pacific Oscillation data value indicates a spatial pattern created by a La Niña. The greater the values, the closer the resemblance to the El Niño- and La Niña-like spatial patterns in sea surface temperature anomalies. That's why the year-to-year variations in the Interdecadal Pacific Oscillation data mimic a commonly used index for the strength, frequency and duration of El Niño and La Niña events (NINO3.4 region sea surface temperature anomalies), as shown in Figure 3.6-2. For two climate-related datasets, they agree quite strongly for climate-related datasets, with a correlation coefficient of 0.93.

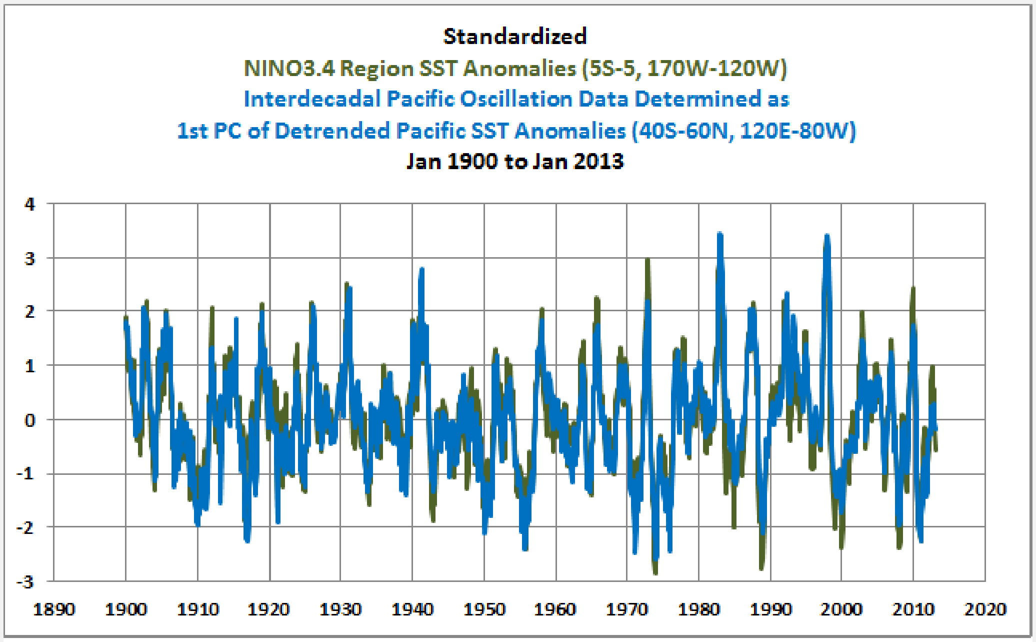

Figure 3.6-2

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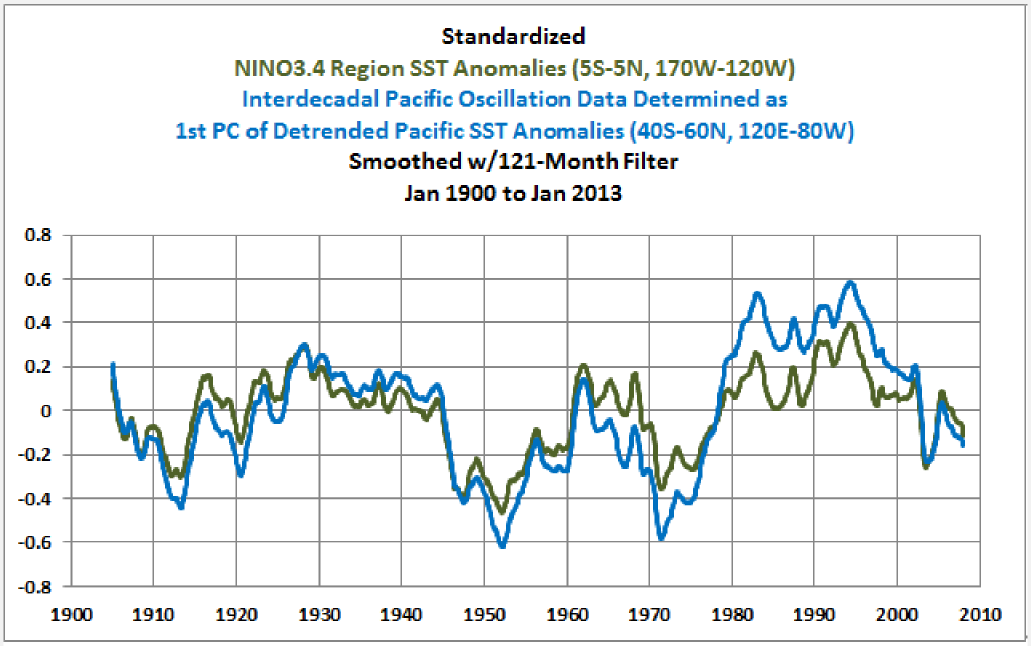


Figure 3.6-3

But it's also easy to see in my Figure 3.6-2 that there are subtle differences in the annual variations. We can highlight these minor differences by smoothing both datasets with 121-month running-average filters. See Figure 3.6-3. Even with the decadal smoothing, the variations agree quite well. The additional variability of the Interdecadal Pacific Oscillation data is likely caused by the effects of changes in wind patterns (and the interdependent changes in sea level pressure) outside of the tropical Pacific that are not related to El Niño and La Niña processes. Changes in the direction and speeds of winds also impact the spatial pattern of sea surface temperature anomalies.

Of course, some of the differences could also be caused by the uncertainties of the data. Keep in mind, sea surface temperature data are reconstructions—that is, we're not examining raw sea surface temperature data—and numerous corrections and adjustments have been made that can impact these results.

Note: The Interdecadal Pacific Oscillation is presented, again depending on the paper, using a number of different low pass filters. I've used a 121-month running mean because it's easy to understand and easy to duplicate, for those wishing to confirm the results. [End note.]

There are a couple of sea surface temperature-based ENSO indices (which represent the timing, strength and lengths of El Niño and La Niña events). And as shown in Figure 3.6-4, if we use the sea surface temperature anomalies for the Cold Tongue Region (6S-6N, 180-90W) as our ENSO index instead of the NINO3.4 sea surface temperature anomalies (5S-5N, 170W-120W), we get slightly different results on the timing of the changeovers from El Niño to La Niña dominance. So the results are also dependent on the ENSO index.

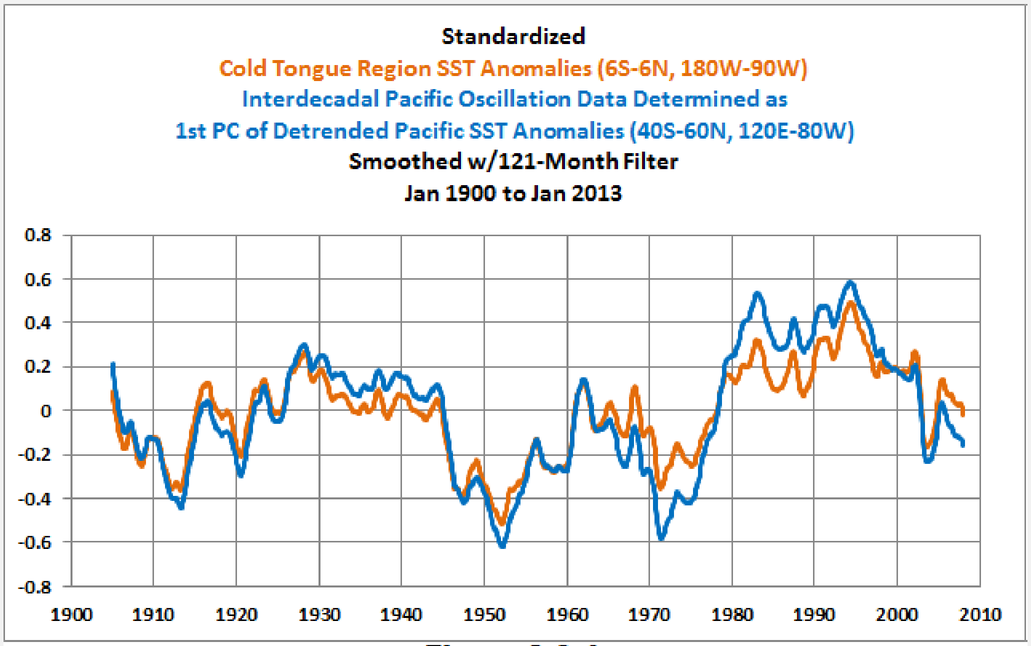


Figure 3.6-4

Bottom line, as the comparisons show in Figures 3.6-3 and 3.6-4, for the most part, during periods when El Niño events dominate, the Interdecadal Pacific Oscillation data are positive and when La Niñas dominate, the Interdecadal Pacific Oscillation data are negative. It was those minor differences that interested researchers, because they influenced rainfall patterns in Australia.

As you'll note in Figures 3.6-3 through 3.6-4, there are no units in those graphs. That is, they do not present sea surface temperature anomalies. The reason: the two datasets have been standardized, divided by their standard deviations, so that they're easier to compare. I've included Figure 3.6-5 as a reference. It compares NINO3.4 sea surface temperature anomalies to the 1st Principal Component of the detrended sea surface temperatures of the Pacific (Interdecadal Pacific Oscillation data) without the standardization. Based on their standard deviations, the variations in the NINO3.4 sea surface temperature data are about 8 times stronger than the not-standardized Interdecadal Pacific Oscillation data.

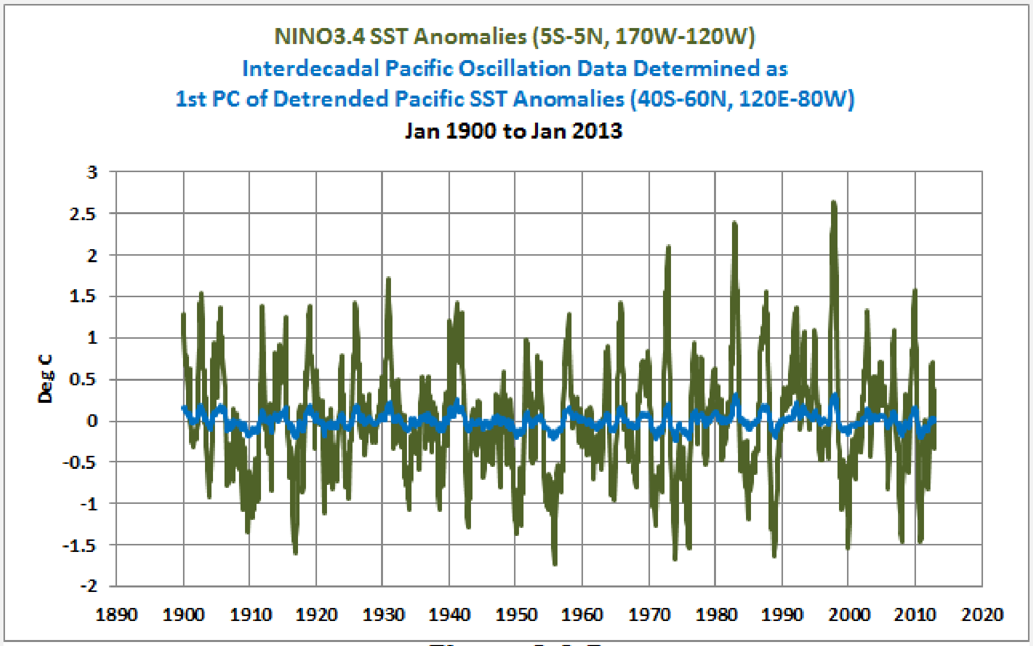


Figure 3.6-5

As noted earlier, there is an Interdecadal Pacific Oscillation dataset available on the internet. The version updated in 2008 is here. It's based on the 1999 paper by Power et al. Inter-decadal Modulation of the Impact of ENSO on Australia. Unfortunately, it ends in 2008.

To provide an up-to-date version, I used HADISST sea surface temperature data for the Interdecadal Pacific Oscillation in Figures 3.6-2 to 3.6-5. HADISST is a commonly used sea surface temperature dataset for these types of analyses. The problem: the HADISST data is infilled using EOF analysis. So the Interdecadal Pacific Oscillation data I presented was based on an EOF analysis of a dataset that was infilled using EOF analysis. In other words, Interdecadal Pacific Oscillation data based on HADISST data also reflects, in part, the infilling method.

Ideally, I would have used HADSST3 data because it is not infilled. But that creates another problem because the HADSST3 data is not spatially complete—there are grids without data or gaps in the data—and this is especially true in the South Pacific. This presents a problem when performing EOF/PC analyses. At the KNMI Climate Explorer, the default setting for the analysis requires that certain percentage of the grids contain data. For the months that don't reach that threshold, the KNMI Climate Explorer leaves a blank, no output. That leaves numerous gaps in the Interdecadal Pacific Oscillation data during the 1940s and little data prior to the 1920s.

There are subtle differences between the Interdecadal Pacific Oscillation dataset I created and the "official" Interdecadal Pacific Oscillation data. I've compared them in Figure 3.6-6 for your information. Regardless, when El Niños dominate, the Interdecadal Pacific Oscillation is generally positive and when La Niñas dominate, the Interdecadal Pacific Oscillation is generally negative. And as discussed earlier, the differences are likely caused by the other factors that influence the ENSO-related spatial patterns in the Pacific.

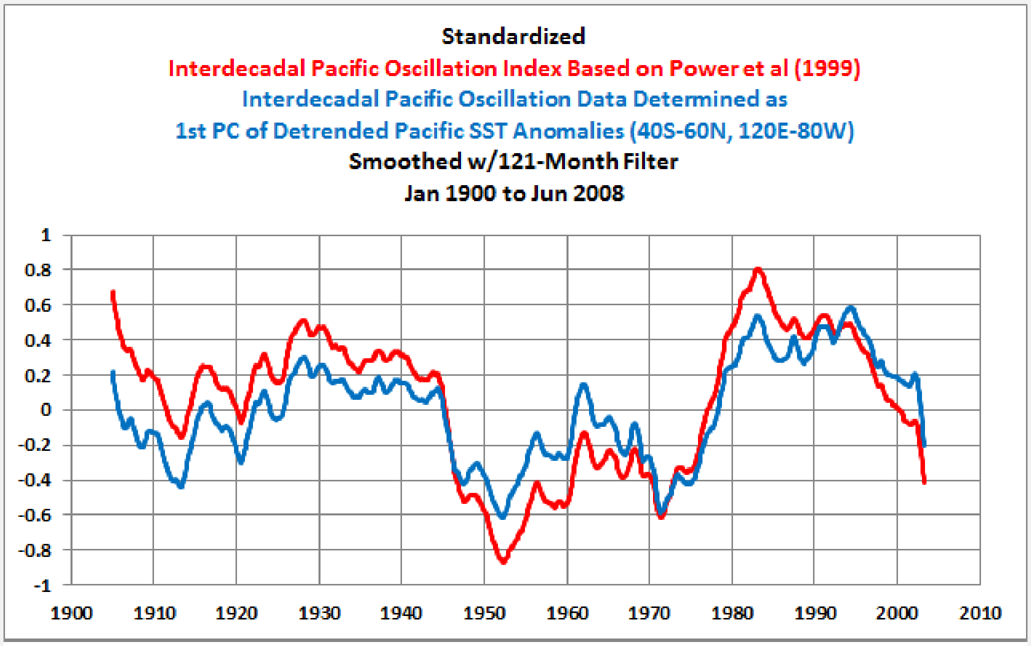


Figure 3.6-6

And of course, as shown in Figure 3.6-7, the yearly variations in the "official" Interdecadal Pacific Oscillation data mimic the variations in NINO3.4 sea surface temperature anomalies—our ENSO (El Niño and La Niña) index.

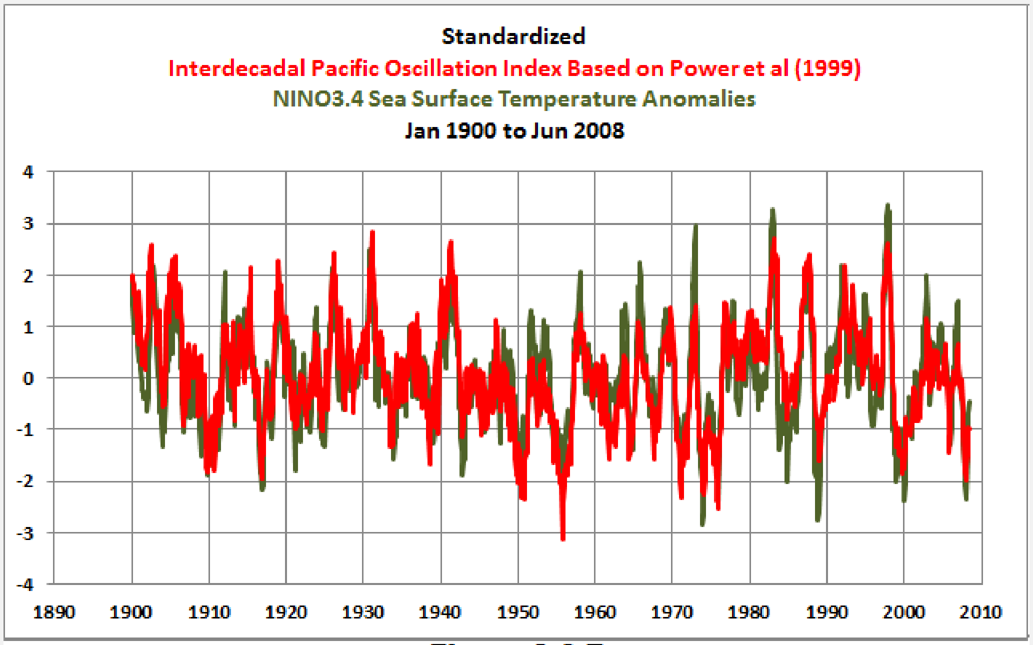


Figure 3.6-7

The document that contains the "official" Interdecadal Pacific Oscillation data includes the following statement:

> *The physical nature of the IPO is under investigation; it is still not clear, despite the above studies, to what extent the IPO is really independent of ENSO red noise and especially of SST variations near a decadal time scale where some physical processes have been identified.*

That webpage has obviously not been updated since 2008. Since then, Shakun and Shaman (2009) Tropical origins of North and South Pacific decadal variability examined the data in the North and South Pacific using EOF analyses. The conclusions of Shakun and Shaman (2009) reads (Note PDV stands for Pacific Decadal Variability):

> *Deriving a Southern Hemisphere equivalent of the PDO index shows that the spatial signature of the PDO can be well explained by the leading mode of SST variability for the South Pacific. Thus, PDV appears to be a basin-wide phenomenon most likely driven from the tropics. Moreover, while it was already known PDV north of the equator could be adequately modeled as a reddened response to ENSO, our results indicate this is true to an even greater extent in the South Pacific.*

To sum up this section, the Interdecadal Pacific Oscillation is simply another El Niño- and La Niña-related index. When smoothed with decadal (or longer) filters, it portrays the decadal and multidecadal variations in the dominance of El Niño and La Niña events. The variations in the Interdecadal Pacific Oscillation index and two ENSO indices (NINO3.4 and Cold Tongue Index sea surface temperature anomalies) agree quite well on annual and decadal time scales.

Unfortunately, many persons misunderstand what the Interdecadal Pacific Oscillation represents.

WHAT THE INTERDECADAL PACIFIC OSCILLATION DOES NOT REPRESENT

While the Interdecadal Pacific Oscillation data is derived from the sea surface temperature anomaly data of the Pacific Ocean, it does not represent the sea surface temperature anomalies there. The Interdecadal Pacific Oscillation data also does not represent the multidecadal variations in the sea surface temperatures of the Pacific Ocean. To confirm that, Figure 3.6-8 compares the "official" Interdecadal Pacific Oscillation data to detrended sea surface temperature anomalies of the Pacific Ocean (40S-60N, 120E-80W). Note again that the data in Figure 3.6-8 have been standardized, which greatly exaggerates the variations in both.

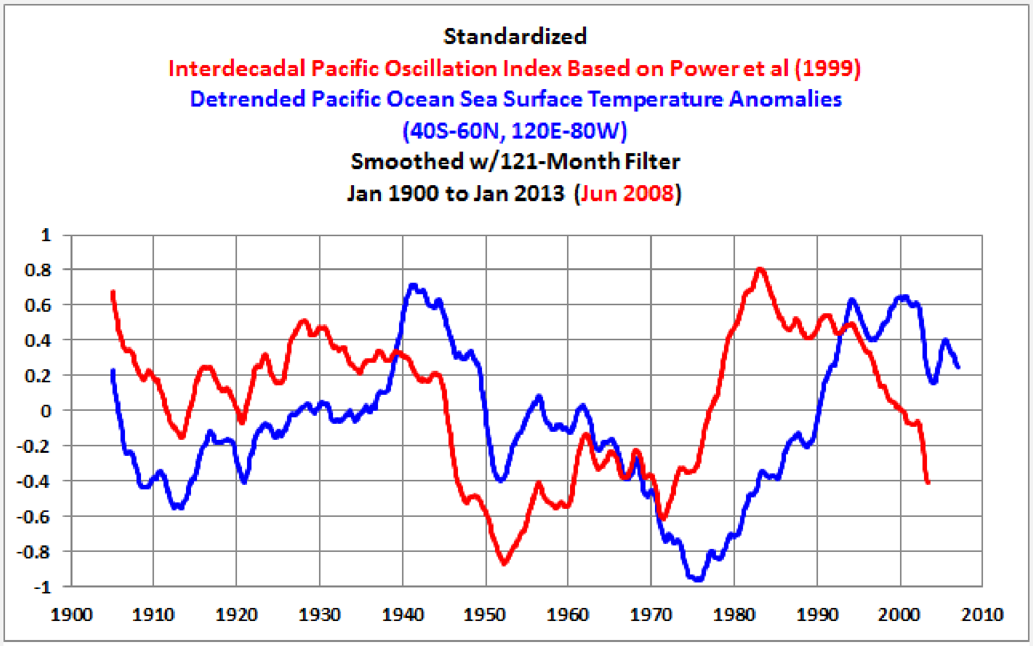


Figure 3.6-8

Note: If you're not familiar with the multidecadal variations of the detrended sea surface temperature anomalies for the Pacific Ocean, they are mimicked by the variations in the detrended global sea surface temperature anomalies. That makes sense because the Pacific Ocean is such a large part of the global oceans. See Figure 3.6-9. The data in Figure 3.6-9 have not been standardized.

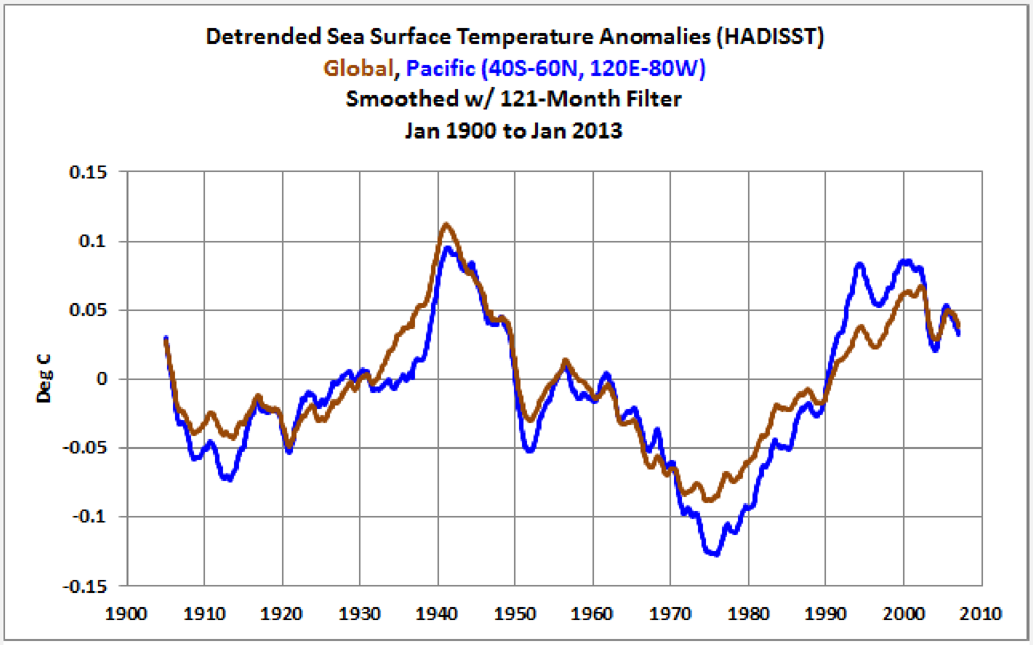


Figure 3.6-9

[End note.]

CHAPTER SUMMARY

The Interdecadal Pacific Oscillation data was created to help explain why El Niño and La Niña events had certain impacts on Australian weather in some time periods and different impacts during other periods.

The Interdecadal Pacific Oscillation is a statistically created dataset that represents how closely the sea surface temperature anomaly spatial pattern of the Pacific Ocean basin resembles the pattern created by El Niño and La Niña events. The closer the spatial pattern is to resembling one caused by El Niño (La Niña) events, the higher (lower) the PDO value is above (below) zero. And while the Interdecadal Pacific Oscillation data are derived from the sea surface temperature anomalies of the Pacific Ocean, the Interdecadal Pacific Oscillation data do not represent the sea surface temperature anomalies there.

3.7 – Ocean Mode: El Niño and La Niña

El Niño and La Niña events are typically described as an unusual warming (El Niño) and cooling (La Niña) of the sea surfaces of the central and eastern tropical Pacific. They take place at random time intervals along the central and eastern equatorial Pacific, usually occurring every 2 to 7 years. But there is much more to El Niño and La Niña events. How they operate—their processes—are important, because, combined, they can create long-term global warming…naturally.

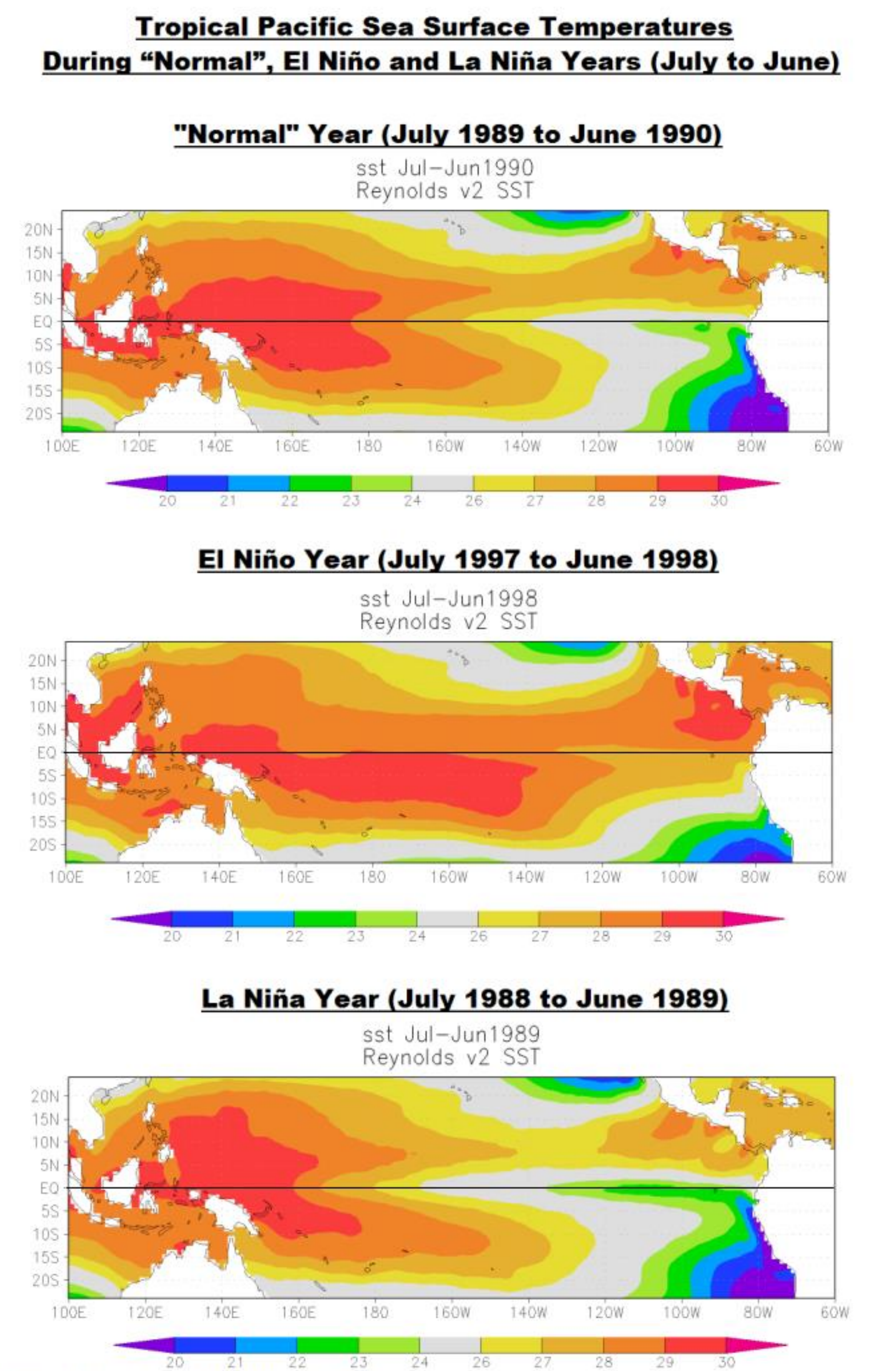
EL NIÑO AND LA NIÑA EVENTS ARE FELT AROUND THE GLOBE

El Niño and La Niña events are parts of coupled ocean-atmosphere processes that enhance or suppress the distribution of heat (atmospheric and ocean circulation) from the tropical Pacific to high latitudes. As such they help to regulate the temperature difference between the tropics and the poles. El Niños and La Niñas also impact atmospheric and ocean circulation in other ocean basins and throughout the globe. They are often described as the dominant mode of natural variability on Earth. As such, you can find evidence of them in many datasets, from global surface temperatures to precipitation.

IMPACTS OF EL NIÑO AND LA NIÑA ON THE SURFACE OF THE EQUATORIAL PACIFIC

The three maps in Figure 3.7-1 show the annual sea surface temperatures (not anomalies) for the tropical Pacific associated with a "normal" year (top), which in this example was 1989/90, and two strong events: the 1997/98 El Niño (middle), and the 1988/89 La Niña (bottom). You'll notice that the 12-month average sea surface temperatures cover the periods of July to June. This was done because El Niño and La Niña events normally peak in November-December-January. Most times, an explanation of El Niño and La Niña events will start with maps of sea surface temperature anomalies. I've elected to start with absolute temperatures, because processes that drive El Niños and La Niñas are based on absolute temperatures, not anomalies. Critical to that discussion is the temperature difference (absolute, not anomalies) between the eastern and western equatorial Pacific. We'll present sea surface temperature anomalies afterwards.

Because El Niño and La Niña events are focused on the equator, I've highlighted it with a thin black line.



Maps Created at KNMI Climate Explorer

Figure 3.7-1

During an El Niño (middle map), warm water from the western tropical Pacific floods eastward along the equator, and ocean processes carry that warm water away from the equator. A La Niña (bottom map) is an exaggerated "normal" state of the tropical Pacific, during which more cool waters from below the surface than "normal" are being drawn to the surface (upwelled) along the central and eastern equatorial Pacific. The "normal" state of the tropical Pacific (top map) is important because it sets the stage for El Niño and La Niña events.

In the top map, notice the normal temperature difference between the eastern and western equatorial Pacific. Based on the temperature scale, the annual average water temperature in the western tropical Pacific is normally about 5 deg C (about 9 deg F) warmer than in the eastern equatorial Pacific. That temperature difference is caused by sunlight and the trade winds. As discussed in Chapter 3.2 – Introduction to Ocean Circulation, the trade winds traveling from east to west in the tropical Pacific (both hemispheres) drive the North and South Equatorial Currents, which carry surface waters from east to west the full length of the tropical Pacific.

And as you'll remember, the tropical Pacific stretches almost halfway around the globe. Sunlight, which is strongest in the tropics, warms that water as it makes the long journey westward. Along the equator in the eastern Pacific, cool subsurface waters are being drawn to the surface by the trade winds in a process called upwelling. Those cool upwelled waters from the east are then warmed by the sun as they travel slowly west. Indonesia and Australia restrict the westward migration of the warm water, so it collects in the western tropical Pacific in a region logically called the West Pacific Warm Pool. The region in the eastern equatorial Pacific also has a name. It's called the Cold Tongue Region for obvious reasons.

Notice how the temperature difference between the eastern and western equatorial Pacific decreases during the El Niño year. In the "normal" year, the annual east-to-west temperature difference was about 5 deg C (about 9 deg F), but in the El Niño year, the temperature difference between east and west (along the equator) has dropped to the neighborhood of 1.5 deg C (about 2.7 deg F). See the graph in Figure 3.7-2.

The y-axis (vertical axis) in the illustration is temperature (not anomalies) in deg C, and the x-axis (horizontal axis) is longitude for the equatorial Pacific, with Indonesia to the left and Ecuador to the right.

Also notice in the lower map in Figure 3.7-1 (above) how, during the La Niña, the temperature difference increases between the eastern and western equatorial Pacific. The Cold Tongue Region has extended to the west, and the West Pacific Warm Pool has been pushed farther to the west as well. As a result, the temperature difference between the east and west equatorial Pacific is about 1 deg C (1.8 deg F) greater during the La Niña than in the "normal" year. Refer again to the graph in Figure 3.7-2.

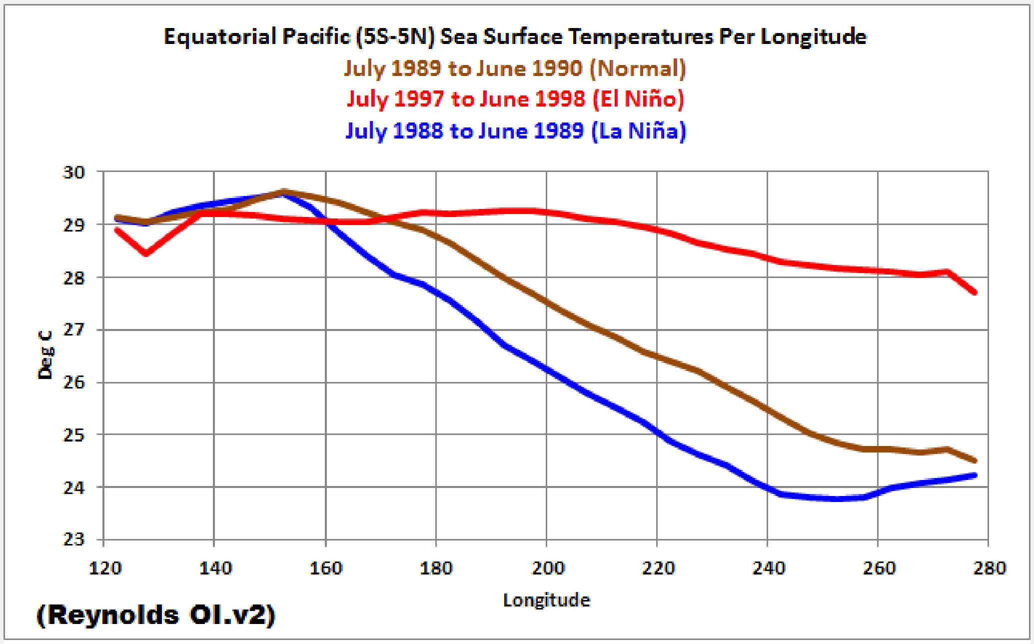
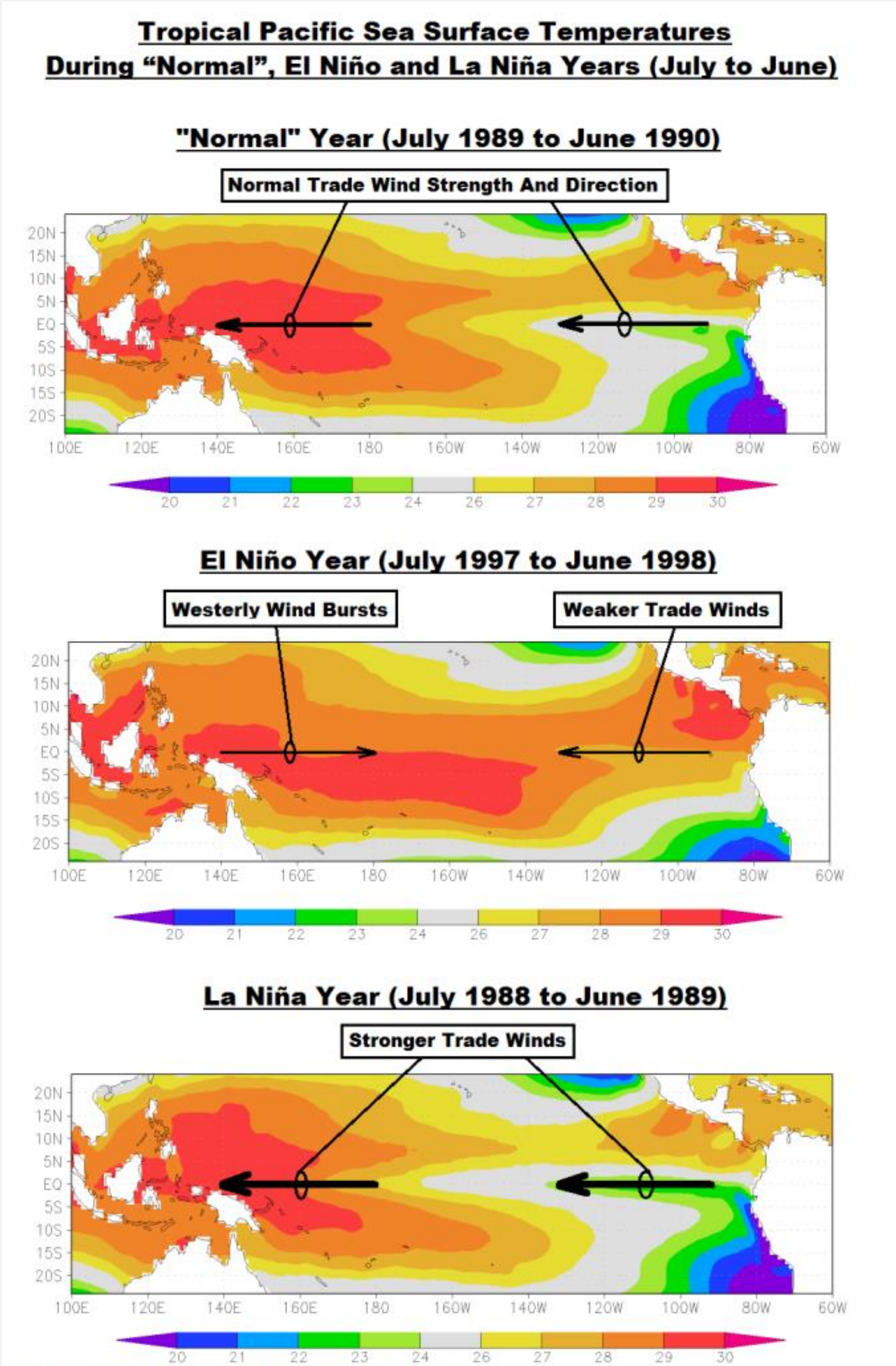


Figure 3.7-2

The graph in Figure 3.7-2 above shows the sea surface temperature gradients from west to east across the equatorial Pacific (5S-5N) during (1) the "normal" year of July 1989 to June 1990 (brown curve), (2) the El Niño year of July 1997 to June 1998 (red curve), and (3) the La Niña year of July 1989 to June 1989 (blue curve). They correspond to the three maps of the three years in Figure 3.7-1. The warmest water during the "normal" and La Niña years resided at about 155E in the West Pacific Warm Pool, while during the 1997/98 El Niño, the warmest water has shifted east almost ¼ of the way around the globe to about 165E longitude. Keep in mind that the El Niño and La Niña events illustrated in the graph and in the maps are very strong. It's rare when El Niños and La Niñas create changes that great along the equator in the Pacific.

Now you're probably wondering what causes the sea surface temperatures to change that much from "normal" conditions, to El Niño conditions, to La Niña conditions and back to "normal" conditions.

THE SEA SURFACE TEMPERATURES OF THE EQUATORIAL PACIFIC ARE COUPLED WITH THE TRADE WINDS



Maps Created at KNMI Climate Explorer

Figure 3.7-3

I've added a few arrows to those same maps in Figure 3.7-3. They represent the strengths and directions of the trade winds during the three modes of the tropical Pacific. Note the similarities between the "normal" conditions (top map) and La Niña year (bottom map). The trade winds are blowing in the normal direction, from east to west. The difference is the strength of the trade winds. During the La Niña phase, the stronger trade winds cause more cool subsurface waters than normal to be upwelled to the surface, which results in lower sea surface temperatures along the equator.

As we discussed in Chapter 3.2 – Introduction to Ocean Circulation, the trade winds blow from the mid-latitudes toward the equator in both hemispheres because the ocean surface is warmer near the equator than it is at the mid-latitudes. The warm and moist air at the equator rises and draws in cooler air from the mid-latitudes, with the surface winds, to replace the rising air. Because the Earth is spinning, those surface winds are deflected toward the west, creating the trade winds.

The temperature difference between the eastern and western equatorial Pacific can also strengthen or weaken the trade winds. Because the water is warmer in the western tropical Pacific, more warm and moist air rises there (low sea level pressure), drawing more air from east to west. And because the water is cooler in the eastern equatorial Pacific, the air tends to drop toward the surface there (high sea level pressure). The surface winds blow from the region with high sea level pressure to the low sea level pressure. As a result, the trade winds are strengthened by a greater temperature difference between east and west along the equatorial Pacific, and, conversely, a smaller temperature difference weakens the trade winds.

But the opposite can be said when discussing trade wind strength. Stronger trade winds along the equator in the Pacific create a greater temperature difference from east to west, and weaker trade winds result in a smaller temperature difference. So the surface temperatures and trade winds strength are said to be coupled. They interact, and they are interdependent. The temperature difference and the strength of the trade winds provide positive feedback to one another. That positive feedback is called Bjerknes Feedback, which was named after Jacob Bjerknes, a Norwegian meteorologist.

While a La Niña is simply an exaggerated "normal" state, an El Niño is a truly anomalous state. The trade winds in the western Pacific slow and periodically reverse in what are called westerly wind busts. On the surface and below the surface, the warm water from the West Pacific Warm Pool floods eastward…sometimes as far as the coast of the Americas. This raises the sea surface temperatures of the central and eastern equatorial Pacific.

IMPACTS OF EL NIÑO AND LA NIÑA BELOW THE SURFACE OF THE EQUATORIAL PACIFIC

There is at least as much taking place below the surface of the equatorial Pacific as there is at the surface during El Niño and La Niña events. Temperature profiles of the equatorial oceans are shown in Figure 3.7-4. That is, they are color-coded cross-sections of the temperatures below the equator in the Indian Ocean (left-hand region), Pacific Ocean (middle region), and Atlantic Ocean (right-hand region). We'll be concentrating on the Pacific. The vertical white "stripes" separating the oceans are land masses. The horizontal axis (x-axis) of each is scaled in degrees longitude. You'll notice that their vertical axes (y-axes) have two scales, with the top regions stretching from the surface to a depth of 300 meters (almost 1000 feet) and the bottom regions running from 300 meters to 5000 meters (980 feet to 16400 feet). The reason for the split scale: El Niño and La Niña events have the greatest impacts on the top 300 meters. The cross sections are from the European Centre for Medium-Range Weather Forecasts (ECMWF), specifically their Ocean Reanalysis "XZ Monthly" webpage.

The warm waters are in red and the cool waters are shown in blue. Let's concentrate on Pacific Ocean in the top illustration to start. It captures the temperature profile for a "normal" December (December 1989), which is not considered to be El Niño or La Niña conditions. Note how the warm water is much deeper in the western equatorial Pacific than in the eastern portion. Cool waters are upwelled to the surface in the east; the trade-wind-blown equatorial currents carry the water to the west under the equatorial sun, warming it as is goes; and the warm water "piles up" in the western equatorial Pacific. The sea level height during normal conditions is about 0.5 meters (about 1.5 feet) higher in the western equatorial Pacific than in the east.

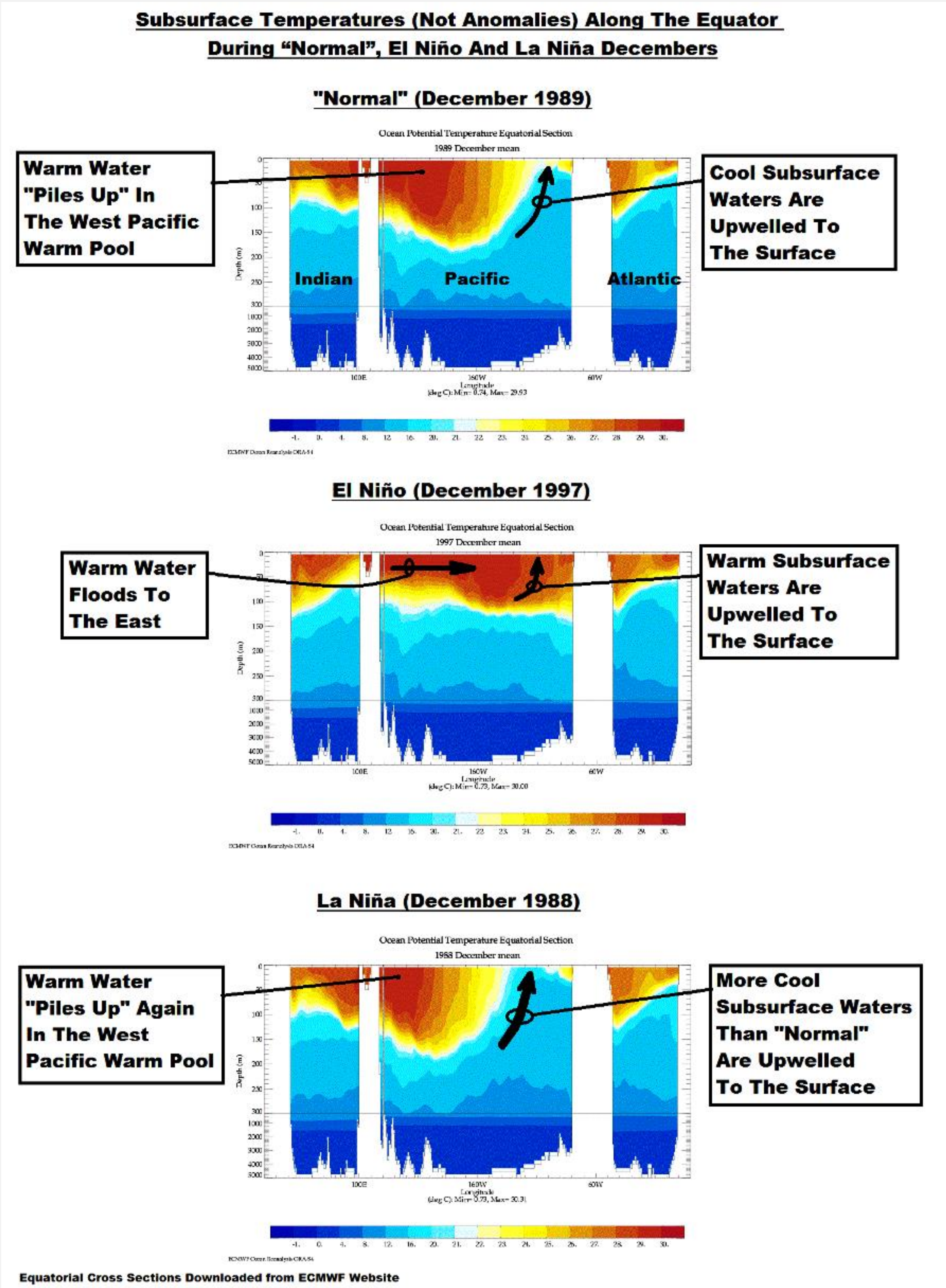

Subsurface Temperatures (Not Anomalies) Along The Equator
During "Normal", El Niño And La Niña Decembers
"Normal" (December 1989)
Ocean Potential Temperature Equatorial Section
1989 December mean
Warm Water "Piles Up" In The West Pacific Warm Pool
Cool Subsurface Waters Are Upwelled To The Surface
Indian
Pacific
Atlantic
Depth (m)
100E
160W
60W
Longitude
El Niño (December 1997)
Ocean Potential Temperature Equatorial Section
1997 December mean
Warm Water Floods To The East
Warm Subsurface Waters Are Upwelled To The Surface
La Niña (December 1988)
Ocean Potential Temperature Equatorial Section
1988 December mean
Warm Water "Piles Up" Again In The West Pacific Warm Pool
More Cool Subsurface Waters Than "Normal" Are Upwelled To The Surface
Equatorial Cross Sections Downloaded from ECMWF Website

Figure 3.7-4

That is, the surface of the equatorial Pacific slopes upward from east to west, rising 0.5 meters (about 1.5 feet) over more than 17000 km (more than 10000 miles), the width of the Pacific along the equator. And the boundary separating the cool waters from the warm waters slopes downward from east to west. Those slopes are, of course, caused by the trade winds pushing the sunlight-warmed waters to the west. Nature, however, likes things to be level. If the trade winds were not blowing the surface waters from east to west, there would be no slope in the sea level, and the subsurface temperature profile would flatten, too.

And that's what happens as an El Niño is forming…Mother Nature tries to create a level playing field.

A "westerly wind burst" sends a "pulse" of warm water, below the surface, from west to east along the equator. (The pulse of warm water is called a downwelling equatorial Kelvin wave.) That pulse of warm water "rides" along a relatively fast-moving west to east subsurface current called the Pacific Equatorial Undercurrent, a.k.a. the Cromwell Current. If there is enough warm water carried to the east, when that warm water is upwelled to the surface in the east, it will upset the normal "balance" between the surface temperatures and trade winds. The trade winds in the west then weaken and more westerly wind bursts occur, which allow more warm water (at the surface and below the surface) to flood from the West Pacific Warm Pool to the east. That, in turn, can upset the balance even more, due to positive feedback between surface temperatures and the surface winds, and even more warm water floods eastward. All of those feedbacks were in just the right sequence in 1997 for a "super" El Niño to form. And as you'll note in the center cross section in Figure 3.7-4, so much warm water traveled eastward along the equator in 1997 that the boundary between the warm and cool water sloped upward from east to west in December 1997, the opposite of its normal slope. That is, in December 1997, the warm water was deeper in the eastern equatorial Pacific than in the west. Now recall that the Pacific stretches almost halfway around the globe at the equator and you can start to get a feel for just how monstrously large that El Niño was.

The bottom cross section presents the temperature profile in December 1988, which was at or near the peak of a strong La Niña event. The upwelling of cool water in the eastern equatorial Pacific is greater than "normal" during a La Niña. And the greater upwelling during a La Niña is caused by the stronger trade winds along the surface, which, because of the Bjerknes feedback, is in response to the greater temperature difference.

TROPICAL PACIFIC SEA SURFACE TEMPERATURE ANOMALY MAPS

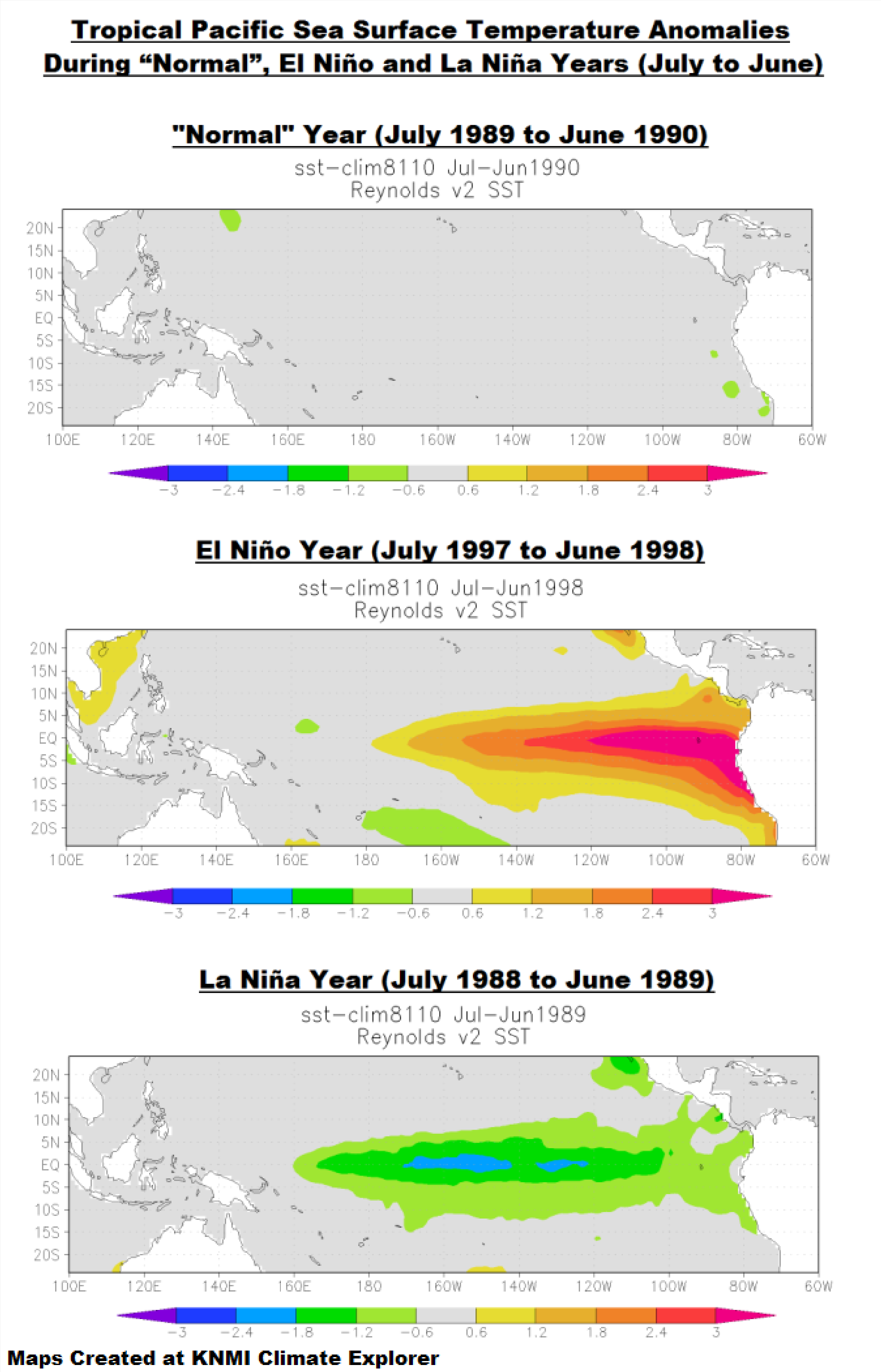


Figure 3.7-5

Most presentations of sea surface temperatures of the tropical Pacific are in anomaly form, so Figure 3.7-5 includes the tropical Pacific sea surface temperature anomalies for those years, referenced to the period of 1981-2010.

The temperature anomalies for the “normal” year of July 1989 to June 1990 (top map) were so small (between -0.6 deg C and +0.6 deg C or about -1.1 deg F to +1.1 deg C) that they didn’t break out of the gray color range on the map. The sea surface temperature anomalies during the El Niño year of July 1997 to June 1998 (middle map) and the La Niña year of July 1988 to June 1989 (bottom map), however, do show the impacts of those events on the sea surface temperature anomalies of the equatorial Pacific.

CENTRAL PACIFIC VERSUS EAST PACIFIC EL NIÑOS

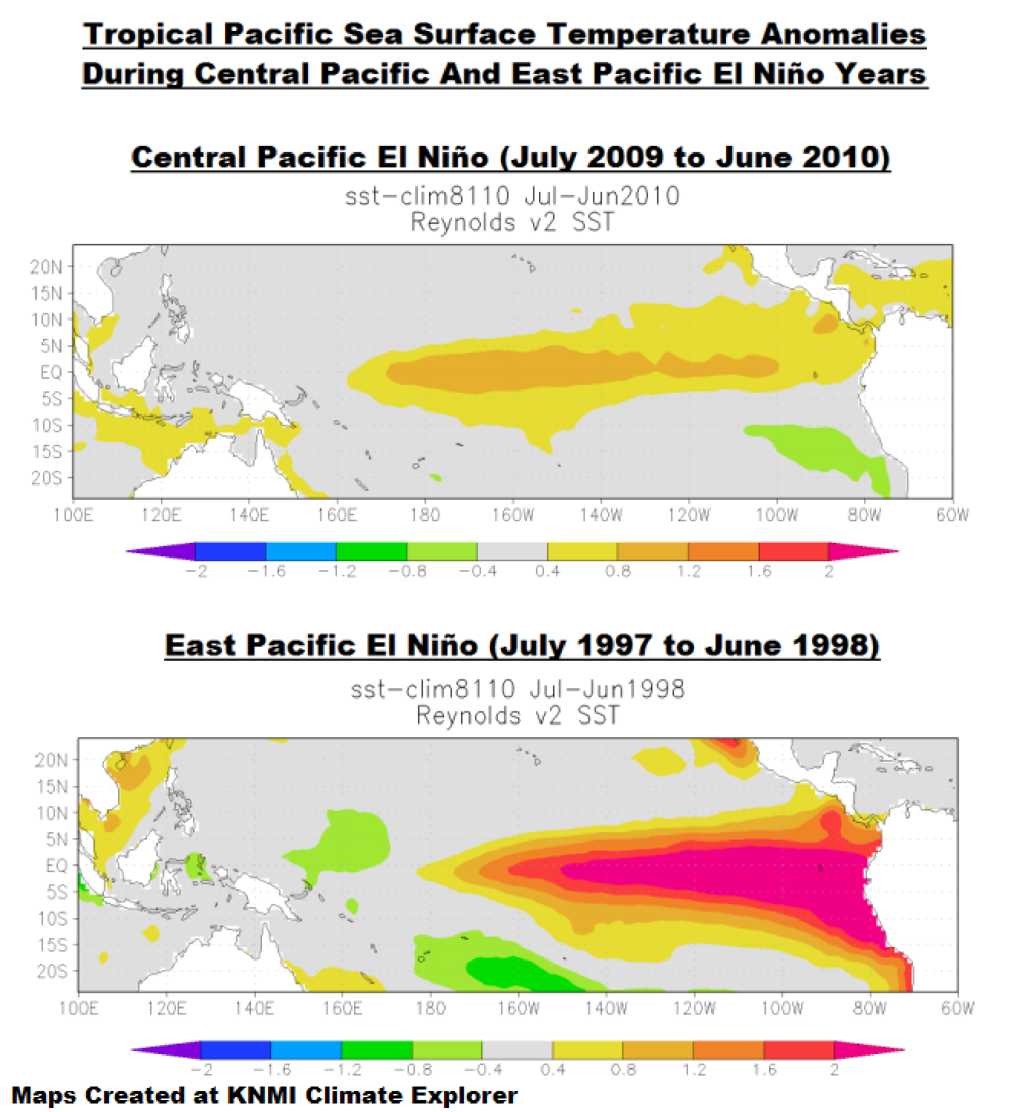


Figure 3.7-6

There are two acknowledged and studied “flavors” of El Niño events. The Central Pacific El Niño, shown in the top map in Figure 3.7-6, and the East Pacific El Niño, the bottom map. But it’s only recently (for the past decade or so) that the two flavors have been acknowledged, and their differences studied. East Pacific El Niño events are typically stronger than the Central Pacific variety. You’ll note for Figure 3.7-6 that I changed the color scaling of the maps (from the earlier maps) to accommodate the lesser magnitude of the Central Pacific El Niño, and that threw sea surface temperature anomalies of the stronger East Pacific El Niño above the upper range value of +2.0 deg C (about +3.6 deg F).

The 2007 paper Ashok et al. El Niño Modoki and Its Possible Teleconnection used sea surface temperature data from three regions in the tropical Pacific to determine if El Niño events were of the Central Pacific variety. Modoki is a Japanese word that means “similar but different”, and El Niño Modoki is used to represent the Central Pacific El Niño, which are similar but different than their stronger East Pacific brethren.

El Niño Modoki (Central Pacific El Niño) events are not new to the tropical Pacific. They have existed there for as long as we have sea surface temperature data. In fact, they occur more often than the stronger East Pacific El Niños. Yet the mainstream media proclaimed them a new type of El Niño brought about man-made global warming, when, in reality, the only thing new was the method used to identify them. Then again, we don’t expect reality from the mainstream media.

IMPACTS OF EL NIÑO AND LA NIÑA ON THE ATMOSPHERE

We’ve discussed the impacts of El Niño and La Niña events on the sea surface temperatures of the tropical Pacific and on the surface temperatures of the equatorial Pacific. They also have very strong impacts on atmospheric circulation patterns.

During “normal” conditions of the tropical Pacific, the sea surface temperatures in the western equatorial Pacific are much warmer than in the eastern equatorial Pacific. The trade winds have piled-up the sunlight-warmed water in the West Pacific Warm Pool, east of Indonesia and north of Australia. Because the water is so warm there, a tremendous amount of evaporation takes place there. All of that warm and moist air rises (convection), it cools, condenses to form clouds, and eventually falls as rain. As a result, the western tropical Pacific has some of the highest rainfall rates in the world. All of that air rising in one place causes an inrush of surface winds, and the trade winds, traveling from east to west across the tropical Pacific, supply that make-up air. Higher up in the atmosphere, the warm and moist air heads from west to east, and it releases moisture and cools along the way. The cooler and dryer air then falls back to the surface in the eastern equatorial Pacific, where the sea surface temperatures are cooler. That circuit is called Walker Circulation or a Walker Cell. See the top cell in Figure 3.7-7.

For those illustrations, I've used the sea surface temperature maps from Figures 3.7-1 and 3.7-3, but I've removed the northern tropical Pacific portions and replaced them with cartoon-like schematics of typical atmospheric circulation patterns for "normal", El Niño and La Niña conditions.

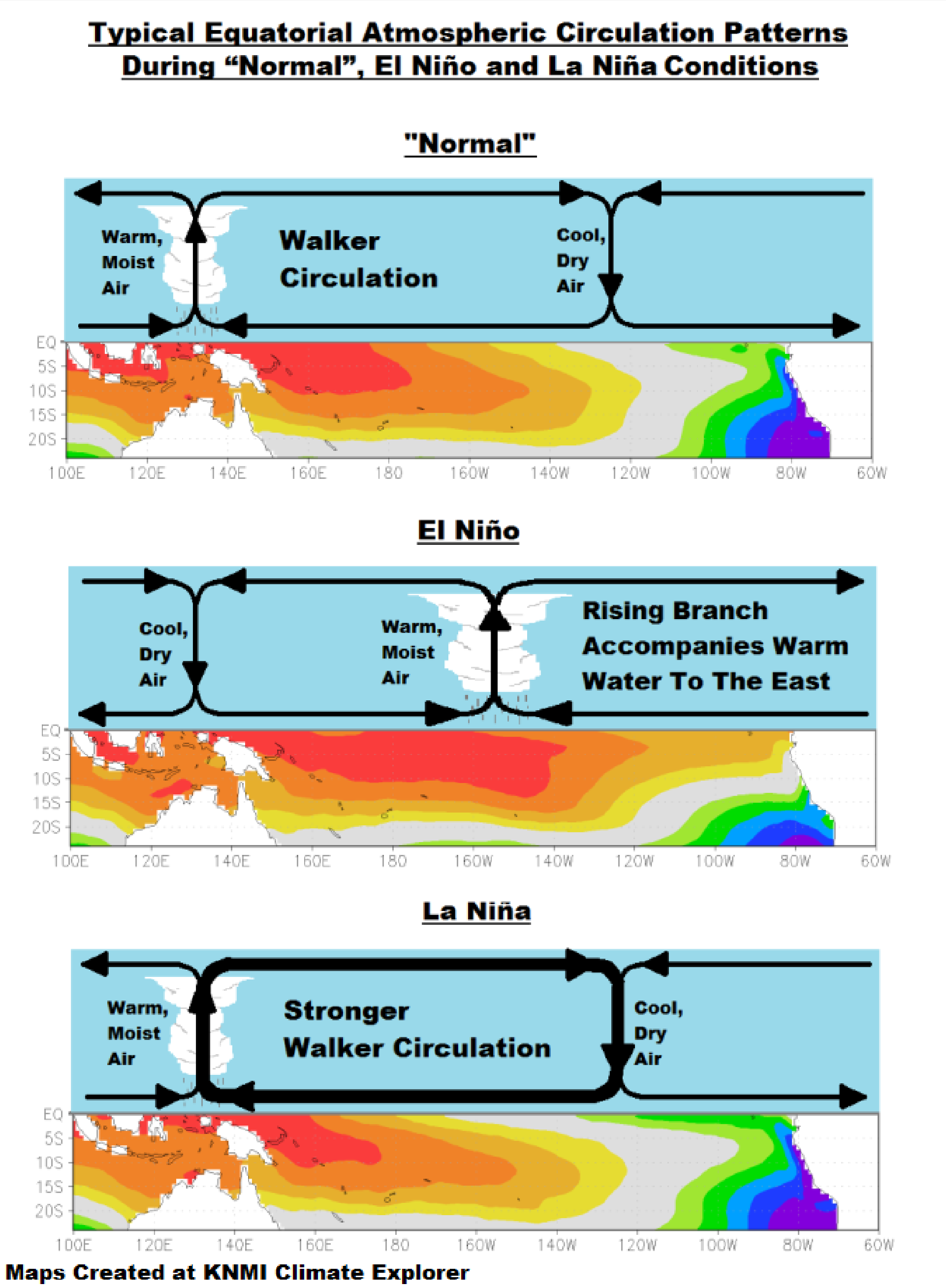


Figure 3.7-7

Everything changes during El Niño conditions.

The warm water that had been in the West Pacific Warm Pool spreads eastward during an El Niño. The convection, cloud cover and precipitation accompany the warm water to the east, so the rising branch of the Walker Cell has moved to the east. The cool, dry air now falls back to the surface in the western tropical Pacific, so the Walker Cell has flip-flopped. As a result, precipitation decreases (and sunlight increases) over Indonesia and Australia during an El Niño. Because a larger surface area of the tropical Pacific as a whole is covered by warmer water during an El Niño, the cloud cover and precipitation also increases over the tropical Pacific…and sunlight reaching the surface of the tropical Pacific as a whole decreases during an El Niño because of the greater cloud cover. But that's also when the tropical Pacific is releasing more heat than normal to the atmosphere.

During a La Niña, conditions along the equatorial Pacific return toward normal conditions but then overshoot that mark and become exaggerated or amplified. The trade winds become stronger than normal over the tropical Pacific. This draws (upwells) additional cool water from below the surface of the central and eastern equatorial Pacific. Because the water is cooler during a La Niña, there is less cloud cover over the central and eastern tropical Pacific. Less cloud cover means more sunlight reaches and enters into the tropical Pacific. That additional sunlight-warmed water is blown to the west by the stronger trade winds, and it accumulates in the western tropical Pacific, in the West Pacific Warm Pool.

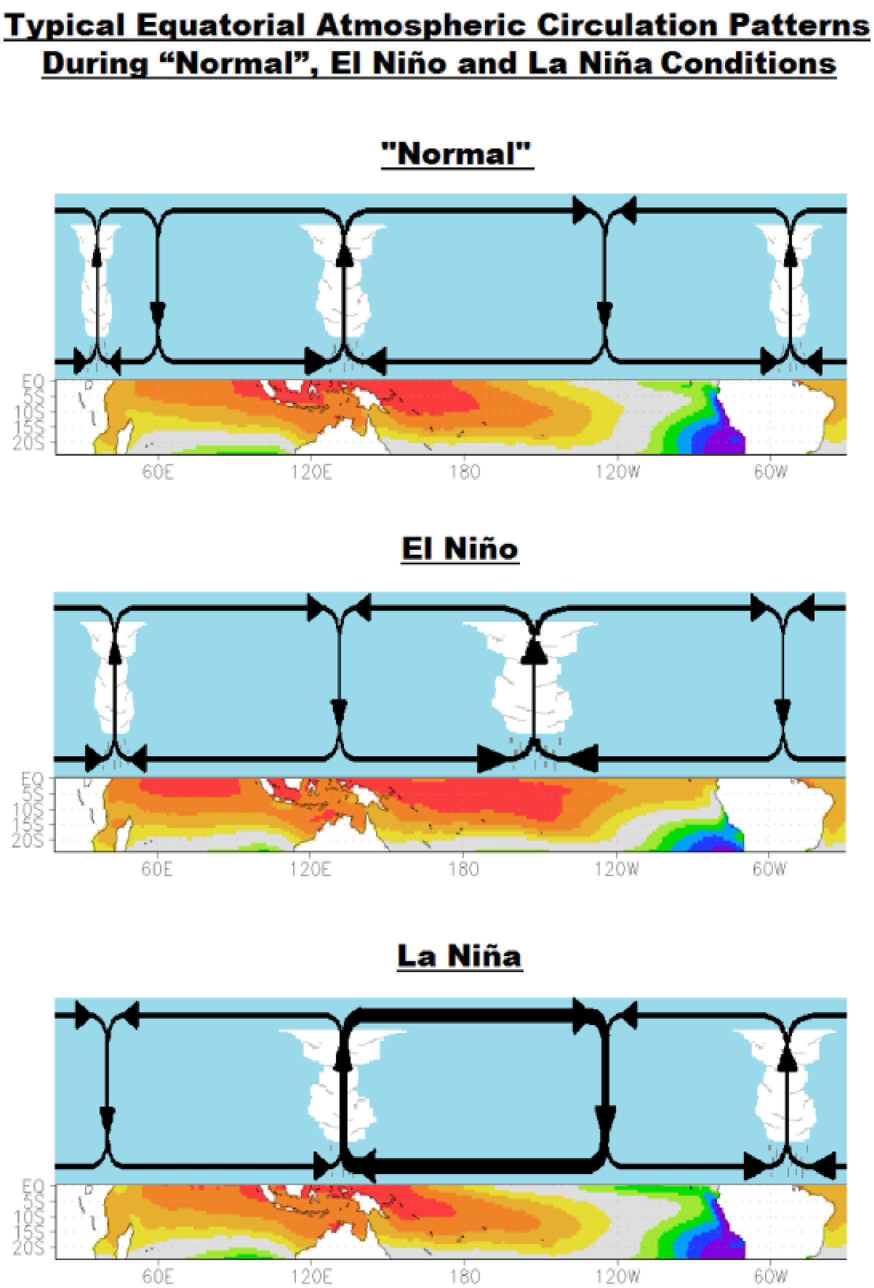
Note: You can find presentations similar to the one above online at numerous websites.

Let's expand our view of atmospheric circulation to include the Indian Ocean to the west and South America to the east. See Figure 3.7-8.

Under normal conditions, top cell, there is the tremendous amount of convection and precipitation over the West Pacific Warm Pool and Indonesia, as discussed above. There is also weaker convection and precipitation over east Africa and South America. For the descending portions of the cells, the cool, dry air sinks back to the surface in the eastern tropical Pacific and in the western Indian Ocean, the Arabian Sea.

During an El Niño, center cell, the convection and precipitation accompanies the warm water eastward to the central equatorial Pacific. That major shift in atmospheric circulation in the equatorial Pacific causes major changes in atmospheric circulation throughout the tropics as a whole. There is an increase in the convection and precipitation over the central and eastern portions of the tropical Pacific…and over East Africa. And the normal convection and precipitation over Indonesia and South America is replaced by sinking cool, dry air during an El Niño.

La Niña conditions are similar to normal conditions, except they're exaggerated. There is more convection and precipitation over the West Pacific Warm Pool, Indonesia and South America. The air is dryer over the eastern tropical Pacific. The circulation also changes over east Africa and the western Indian Ocean. The normal wet conditions over east Africa are replaced by cool, dry conditions, which appear to have shifted to the west during the La Niña.



Maps Created at KNMI Climate Explorer

Figure 3.7-8

Note: The expanded portion of the presentation was recently provided by Tom Di Liberto (a meteorologist from NOAA) at the NOAA ENSO blog. See his post The Walker Circulation: ENSO's atmospheric buddy. I found it to be a very good way to present how El Niño and La Niña events impact atmospheric circulation throughout the tropics, which is why I imitated the NOAA illustrations with my Figure 3.7-8.

Now recall our earlier presentation of atmospheric circulation from tropics to poles and our discussion of the Hadley Cells, Ferrell Cells and Polar Cells. Hadley Circulation is presented in Figure 3.7-9. During El Niño events, a tremendous (an immeasurable) amount of heat is released from the tropical Pacific Ocean to the atmosphere. The vast majority of that heat is released through evaporation. As you'll recall, as the warm, moist air rises it condenses in the cooler upper atmosphere, and as it condenses, turning from a gaseous to liquid state, it releases heat to the atmosphere. (Latent heat is the heat released or absorbed by a substance during a change in its physical state, without a change in its temperature.) It is primarily through latent heat that the heat from the sun (that warmed the tropical oceans to depth) is released into the atmosphere.

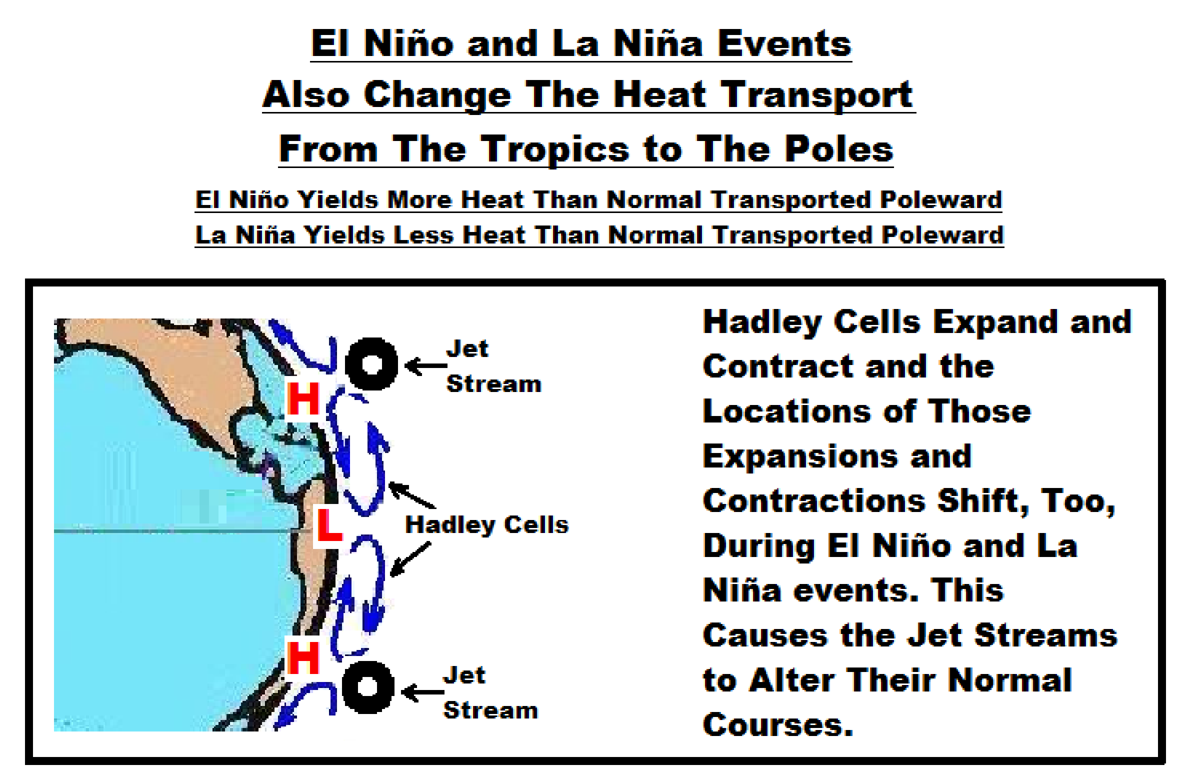


Figure 3.7-9

In response to all of the additional convection and latent heating, Hadley Circulation intensifies during El Niño, and the Ferrell and Polar cells respond in turn so that the extra heat is transported to the poles. Additionally, because the primary location of convection and latent heating has shifted from the West Pacific Warm Pool to the central and eastern tropical Pacific, the most intense Hadley Circulation changes locations, which causes a cascade of changes in the Ferrell and Polar cells. Now recall that the subtropical jet streams reside between the Hadley and Ferrell cells and that the polar jet streams reside between the Ferrell and Polar Cells. All of the variations in the intensities, and locations of the intensities, of atmospheric circulation during El Niños cause the jet streams to change locations as well.

Thus, an El Niño causes atmospheric circulation to change globally, starting in the tropical Pacific and cascading outward. These changes impact where and how much precipitation falls. And it also impacts surface temperatures outside of the tropical Pacific. Some areas around the globe warm during an El Niño and others cool. More areas around the globe warm (and the amount they warm) during an El Niño are greater than the areas that cool (and the amount they cool), so global surface temperatures outside of the tropical Pacific also warm as a whole during an El Niño.

La Niña events also cause changes in atmospheric circulation, and for the many parts of the globe, the resulting changes in temperatures and precipitation around the globe can be the opposite of those that take place during an El Niño.

There are numerous websites that present the impacts of El Niño and La Niña events on regional weather, including:

From United Nations Environment Programme (UNEP)/ GRID-Arendal:

- Climate impacts of El Niño Phenomenon in Latin America and the Caribbean

From Royal Netherlands Meteorological Institute (KNMI)

- Effects of El Niño on world weather

From Australia's Bureau of Meteorology (BOM):

- Risk Management and El Niño and La Niña
- Australian rainfall patterns during El Niño events

From NOAA:

- El Niño Impacts
- El Niño-Southern Oscillation (ENSO) Diagnostic Discussion, which includes their Weekly ENSO Update (pdf)
- Weather Impacts of ENSO

From UK Met Office (UKMO):

- ENSO Impacts

Please keep in mind that the results shown are typical results. That is, during El Niño and La Niña events those weather patterns have a higher probability than normal of occurring, but they do not always happen.

SEA SURFACE TEMPERATURE-BASED EL NIÑO-LA NIÑA INDICES

Climate scientists selected a number of regions along the equator in the Pacific, and have used the sea surface temperature anomalies of those regions as indices for the magnitudes (strengths), frequencies (how often they occur) and duration (how long they last) of El Niño and La Niña events. Those regions are shown in Figure 3.7-10.

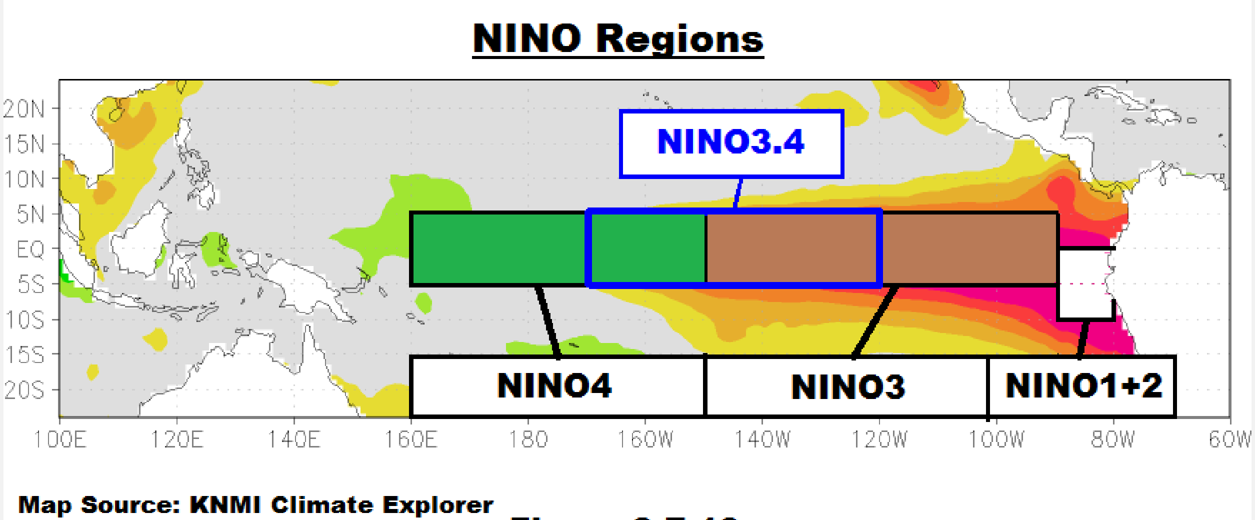


Figure 3.7-10

The coordinates for the NINO regions are, from east to west:

- NINO1+2: 10S-0, 90W-80W
- NINO3: 5S-5N, 150W-90W
- NINO3.4: 5S-5N, 170W-120W
- NINO4: 5S-5N, 160E-150W

Let's put those sizes of regions into perspective, and we'll focus on the NINO3.4 region. At 5 degrees north or south latitude, the NINO3.4 region stretches about 5500 km (about 3400 miles) from east to west. And the distance from 5 south latitude to 5 north latitude is about 1110 km (about 690 miles). (See the NOAA Latitude/Longitude Distance Calculator.) So the surface area of the NINO3.4 region is greater than 6.1 million square km (about 2.3 million square miles). While it's not as big as the smallest continent (Australia at 9.0 million square km or about 3.5 million square miles), it's still a large area. Now consider that El Niño and La Niña events directly impact all four NINO regions—some of which are smaller and some larger than the NINO3.4 region—with the extent of those impacts depending on the event.

If it appears to you that NINO3.4 was an afterthought, you'd be correct. Climate scientists were looking for an index they could use to define El Niño events, and they were not satisfied with the sea surface temperatures of the existing regions. The NINO4 region was too far to the west to be of value. The NINO1+2 region captured East Pacific El Niños but not the Central Pacific variety. So they had been using NINO3 region sea surface temperatures. The NINO3.4 region was proposed because it better represented most El Niño events. See Trenberth (1997) The Definition of El Niño.

NOAA now defines El Niño conditions as sea surface temperature anomalies of the NINO3.4 region equal to or warmer than +0.5 deg C (+0.9 deg F). Conversely, La Niña conditions exist in the tropical Pacific if sea surface temperature anomalies of the NINO3.4 region are equal to of cooler than -0.5 deg C (-0.9 deg F). Notice that I wrote El Niño conditions and La Niña conditions. The equatorial Pacific can wander into El Niño and La Niña conditions without their being a full-fledged El Niño or La Niña. In order for NOAA to consider an event to be an "official" El Niño or La Niña, El Niño or La Niña conditions have to last for an extended time period. NOAA uses a 3-month average of NINO3.4 sea surface temperature anomalies for their Oceanic NINO Index (ONI). They call those 3-month periods "seasons". If the 3-month averages of positive NINO3.4 region temperature anomalies are equal to or greater than +0.5 deg C for 5 sequential "seasons" (3-month periods), NOAA says an El Niño has taken place. The opposite holds true for La Niñas.

Figure 3.7-11 presents the monthly satellite-era sea surface temperature anomalies for the NINO3.4 region, based on NOAA's Optimum Interpolation sea surface temperature data (a.k.a. Reynolds OI.v2). Monthly Reynolds OI.v2 data are available through the KNMI Climate Explorer. I've added horizontal lines at +0.5 and -0.05 deg C (+0.9 and -0.9 deg F), the thresholds of El Niño and La Niña conditions, and color coded the periods when those conditions existed according to the data. (This is one of the graphs I've updated in this chapter.)

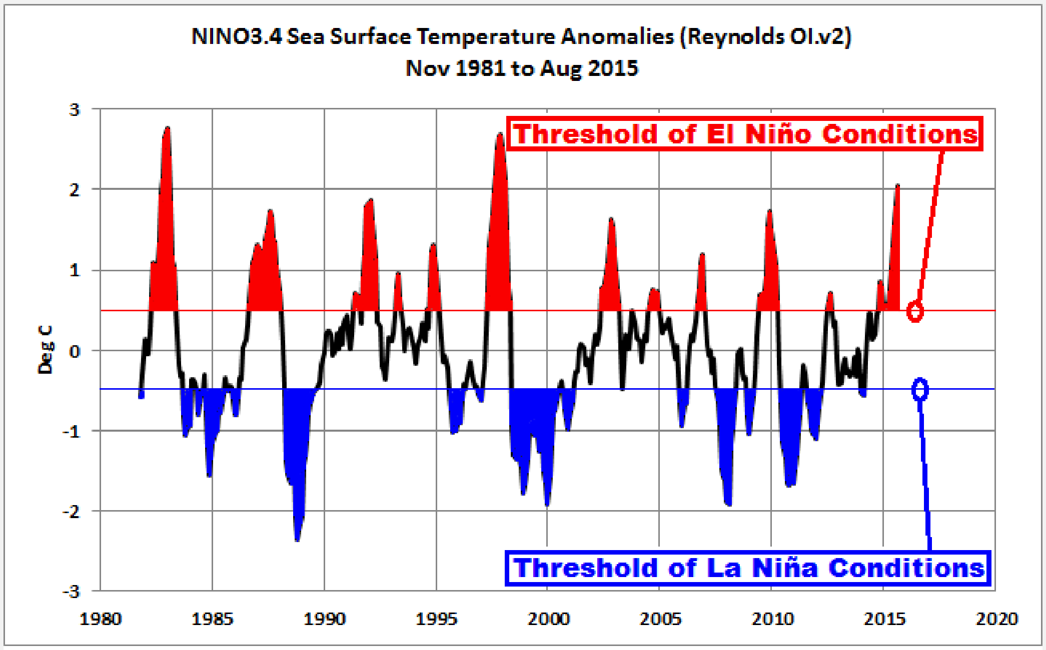


Figure 3.7-11

There are a few things that stand out in the graph of sea surface temperature anomalies for the NINO3.4 region. There were a couple of very strong El Niño events during the satellite era, those in 1982/83 and in 1997/98. They have been classified as "super" El Niños. The 2015/16 El Niño is also evolving to be a very strong El Niño, comparable in strength to those in 1982/83 and 1997/98.

There was also a multiyear El Niño in 1986/87/88. In addition to being a long El Niño, the 1987/88 portion was also relatively strong. On the other hand, the 1988/89 La Niña was the strongest La Niña event during the satellite era, but it wasn't quite as strong as the two "super" El Niños. There was also a multiyear La Niña starting in 1998, which followed the 1997/98 El Niño. And there are back-to-back La Niñas, also known as "double-dip" La Niñas, before and after the 2009/10 El Niño.

You'll note in Figure 3.7-11 that a La Niña does not follow every El Niño. Similarly, an El Niño does not follow every La Niña.

For decades, researchers have been searching for reasons why El Niño and La Niña events occur at those frequencies, strengths and durations, and they still do not have concrete answers. El Niños and La Niñas are simply other examples, extreme examples, of the chaotic nature of climate here on Earth.

Let's extend our view of El Niño and La Niña events back in time and look at long-term reconstructions of sea surface temperature anomalies for the NINO3.4 region. However, whenever we look at climate-related data, we must always keep in mind how little source data (actual observations or measurements) there are before satellites started to fill the gaps. For the equatorial Pacific, the sampling was so poor in the first half of the 20th Century that some sea surface temperature-based El Niño-La Niña indices start in 1950, like NOAA's Oceanic NINO Index (or ONI). The Panama Canal was opened in 1914, and before then, temperature sampling along the equatorial Pacific was even worse. So we'll start this presentation in 1900.

With that in mind, the KNMI Climate Explorer maintains NINO region data from different sea surface temperature reconstructions at their Monthly climate indices webpage. The data for the NINO3.4 region are presented in Figure 3.7-12 (which has also been made current). I've included the linear trends determined by the spreadsheet software on the graph.

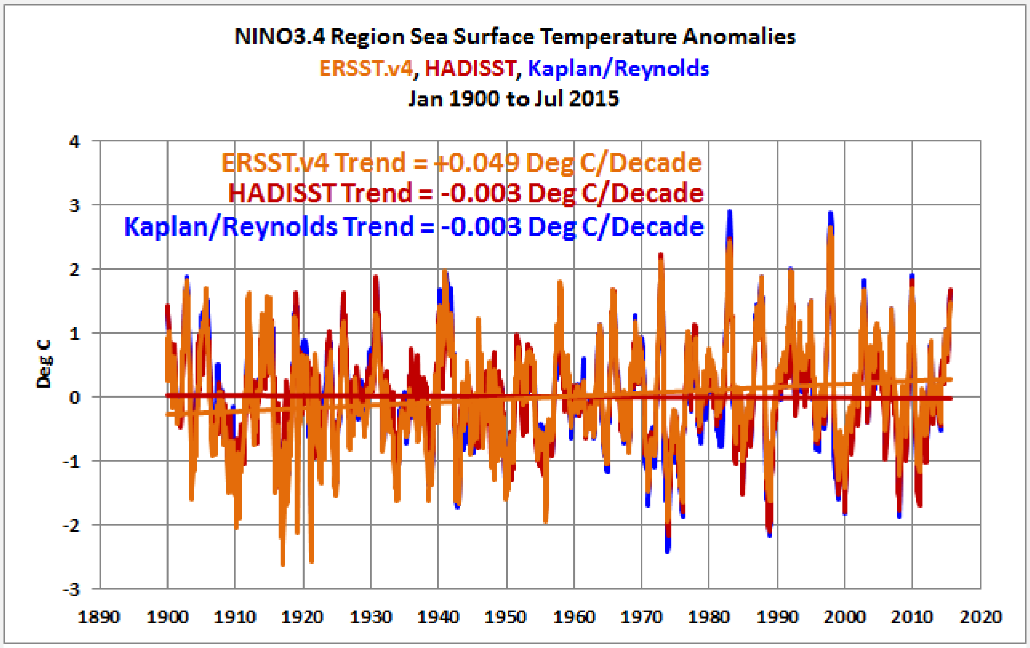


Figure 3.7-12

One of the reconstructions shows no long-term warming, another shows cooling of the sea surfaces of the equatorial Pacific since 1900, while one shows warming. Most of the wiggles occur at the same time; that is, the three datasets are highly correlated.

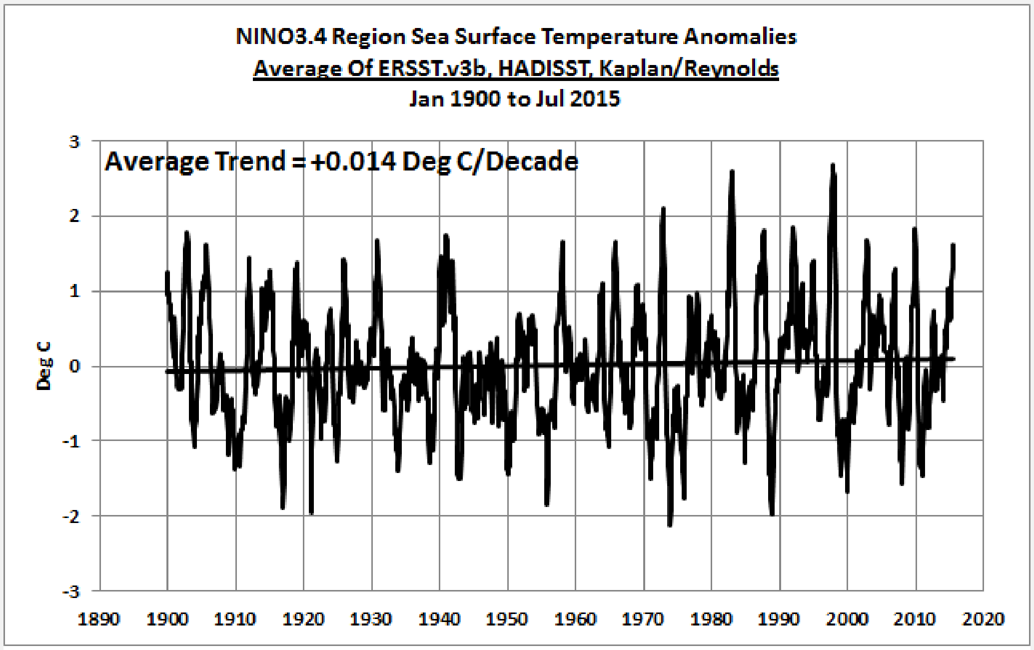


Figure 3.7-13

The average of the three reconstructions is presented in Figure 3.7-13. It shows a very slight warming of the east-central portion of the equatorial Pacific since 1900. You may be wondering how that could be. The surfaces of the global oceans have warmed about 0.65 Deg C (about 1.2 deg F) since 1900 (based on the linear trends of the average of the global ERSST.v4, HADISST and Kaplan/Reynolds data). Why then hasn't the surface of the east-central equatorial Pacific warmed? Recall that the surfaces of the central and eastern equatorial Pacific are being furnished with cool subsurface waters most of the time. That is upwelling is taking place along the equator during "normal" and La Niña phases. The only exceptions to this are El Niño events.

Note: The more recent versions of the reconstructions are showing more and more long-term warming (since 1900) of the eastern and central equatorial Pacific. [End note.]

Something else is evident in the graph. There were three very strong El Niño events starting in the early 1970s—one in 1972/73, one in 1982/83 and one in 1997/98—where before and after that period, El Niño events had not reached 2 deg C (3.6 deg F). That may or may not be true. The 2010 paper by Giese et al. The 1918/19 El Niño argued that the 1918/19 El Niño was comparable in strength to the El Niños of 1982/83 and 1997/98. They also noted that the 1911/12 and 1939-41 El Niños may also have been stronger than shown with the data.

The HADISST NINO3.4 data provides a reasonable representation the average of the three reconstructions, so we'll use it for our long-term NINO3.4 sea surface temperature anomalies. For short-term, we'll continue to use NOAA's Reynolds OI.v2 data.

EL NIÑO-LA NIÑA STRENGTH

The more you study El Niño and La Niña events or discuss them on blogs, the more you'll come across the classifications of weak, moderate and strong events. It's often difficult to find a source that specifies the ranges associated with them. A member of NOAA had classified them in presentation called El Niño Talking Points, which appears to have been given in Southern California. On page 34, you'll discover, during a discussion of La Niña events:

> *Weak is Niño Oscillation Index between -0.5 and -0.9. Moderate between -1.0 and -1.4. Strong is greater than -1.4.*

There's a similar breakdown on page 35 for El Niño events. The El "Niño Oscillation Index" referred to in the presentation is NOAA's Oceanic NINO Index (ONI).

Now consider that the NOAA Oceanic NINO Index is presented in 0.1 deg C increments. So a strong El Niño (La Niña) would be an El Niño (La Niña) with an Oceanic NINO Index value warmer (cooler) than or equal to +1.5 deg C (-1.5 deg C).

HOW DOES AN EL NIÑO OR LA NIÑA BECOME AN "OFFICIAL" NOAA EVENT?

When the sea surface temperatures of the NINO3.4 region warm above a threshold and stays above that threshold for a period of time, it qualifies as an official El Niño and when they cool to levels below a threshold and remain there long enough, the La Niña is considered an official event. According to the NOAA definition, an "official" El Niño event occurs when the Oceanic Niño Index sea surface temperature anomalies exceed +0.5 for 5 straight "seasons" (See clarification below). Likewise, for the cooling of sea surface temperature anomalies in the eastern equatorial Pacific to be considered an "official" La Niña, the Oceanic Niño Index sea surface temperature anomalies must remain lower than -0.5 deg C for 5 straight "seasons". Because the Oceanic Niño Index is a 3-month average of NINO3.4 sea surface temperature anomalies, NOAA normally describes the threshold as 5 straight "seasons", where, for example, Nov-Dec-Jan and Dec-Jan-Feb are considered two consecutive "seasons". Refer to NOAA's Oceanic Niño Index Warm and Cold Events By Season webpage.

THE TERM EL NIÑO-SOUTHERN OSCILLATION OR ENSO

The term El Niño-Southern Oscillation is a hyphenated merger of two terms: El Niño, which we've described already, and Southern Oscillation. The acronym ENSO is also used very widely. El Niño represents the ocean portion of the coupled ocean-atmosphere processes and Southern Oscillation represents the atmospheric portion.

The term El Niño-Southern Oscillation is said to have been coined by Rasmussen and Carpenter in their (1982) paper Variations in Tropical Sea Surface Temperature and

Surface Wind Fields Associated with the Southern Oscillation/El Niño. Let's see what Rasmussen and Carpenter have to say about the individual components. Their Introduction begins with the term El Niño:

> *The interannual variability of sea surface temperature (SST) along the Peru-Ecuador coast is dominated by the El Niño phenomenon. The name El Niño was originally applied to a weak warm coastal current which annually runs southward along the coast of Ecuador around the Christmas season (Wyrtki 1975). In scientific usage, the term has now become more narrowly associated with the extreme warmings which occur every few years (Wyrtki 1979a), and which result in catastrophic effects on the ecological system of the region. In more recent years, Ramage (1975), Weare et al. (1976), and others have used the term to encompass the larger-scale features of the warming event; i.e., the upwelling area along both the equator and the South American coast.*

A few paragraphs later, Rasmussen and Carpenter describe the Southern Oscillation after discussing some initial findings from as far back as 1897:

> *It remained, however, for Sir Gilbert Walker, in a classical series of papers (Walker, 1923, 1924, 1928; Walker and Bliss, 1930, 1932, 1937) to name the SO [Southern Oscillation] and describe the salient features of the surface pressure, temperature and precipitation fluctuations.*

The full title of the first Walker paper is WALKER, G. T. (1923). *Correlation in seasonal variations of weather. VIII. A preliminary study of world-weather. Memoirs of the Indian Meteorological Department 24(Part 4) 75–131*.

These papers by Walker were not discussions of El Niño, however. The link between El Niño and the Southern Oscillation wasn't established until the 1960s. Therefore, the word oscillation in Southern Oscillation does not apply to El Niño and La Niña events or their processes. It only applies to the impacts of El Niño and La Niña on the sea level pressures in Tahiti and Darwin, Australia.

The sequence of papers and the advancement in ENSO research is further described in Rasmussen and Carpenter (1982).

THE SOUTHERN OSCILLATION INDEX

The Southern Oscillation Index, or SOI, is a way to portray the atmospheric component of El Niño and La Niña events. It represents the difference in Sea Level Pressure between Darwin, Australia and the South Pacific island of Tahiti. The term Southern Oscillation was coined by Sir Gilbert Walker in the 1920s. Yes, that's the same Walker as in "Walker Circulation" or "Walker cells". He was the first researcher to note that the surface air pressures in Tahiti and Darwin, Australia opposed one another; that is, when sea level pressure in Tahiti was high, the sea level pressure in Darwin was normally low, and vice versa.

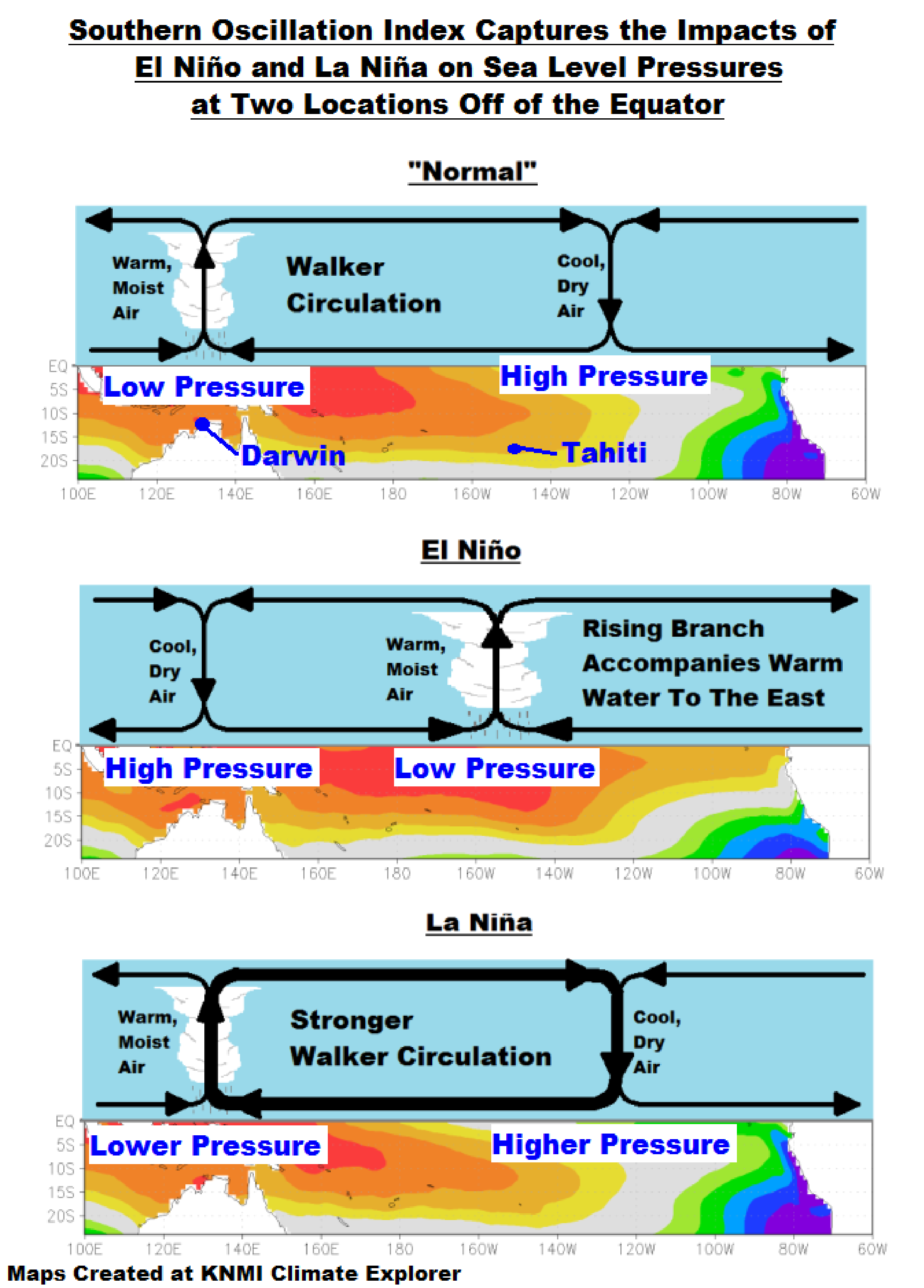


Figure 3.7-14

Let's discuss the trade winds again for a moment. The trade winds are blowing from east to west when the surface air pressure in the east (Tahiti) is higher than in the west (Darwin). See Figure 3.7-14. When the pressure difference between Tahiti and Darwin grows, the trade winds are stronger, and that's normally an indication of a La Niña event. When the sea level pressures reverse, and the sea level pressure in Tahiti is lower than at Darwin, that's normally an indication that an El Niño is taking place along the equator in the Pacific.

I've underlined the word "normally" in those two sentences for a reason. El Niño and La Niña events take place along the equator. But Darwin, Australia is located at 12.5S latitude or about 1390 km (860 miles) from the equator. Tahiti is even farther from the equator: about 1970 km (about 1220 miles) at 17.7S latitude. So Darwin and Tahiti can be impacted by weather that has no relationship to El Niño and La Niña events. That's why researchers went in search of a different index that better represented the timing, strength and duration of El Niño and La Niña events. Refer again to Trenberth (1997) The Definition of El Niño.

The Australian Bureau of Meteorology (BOM) is one of the suppliers of Southern Oscillation Index data. They use a traditional method of presentation, which they explain here. Basically—maybe not so basically—the data is calculated by subtracting the sea level pressure in Darwin from the sea level pressure in Tahiti. Then they determine the anomalies. Here's where the not-so-basically part comes in. The anomalies for that month are divided by the standard deviation, to standardize or normalize the data. After that, they multiply the data by 10. Whew! For those interested, there's a somewhat-simple-to-understand explanation of standard deviation here.

Now that that's out of the way, let's compare the Southern Oscillation index data to the NINO3.4 sea surface temperature anomalies we've been using as an ENSO index. See Figure 3.7-15. Because the Southern Oscillation index data is multiplied by 10 as part of its calculation, we'll need to scale the NINO3.4 sea surface temperature anomalies. A factor of 10 works. The Southern Oscillation index data is noisy, so the two datasets were smoothed with 12-month running-average filters. It's very easy to see the inverse relationship between the two datasets. Equatorial Pacific sea surface temperature warm and cool during the evolution and decay of an El Niño, and Southern Oscillation index data dips and rebounds. The opposite holds true during a La Niña. There are some minor differences. For example, the Southern Oscillation index data shows the 1982/83 El Niño was stronger than the one in 1997/98, while the NINO3.4 sea surface temperature anomalies show them the other way around. Notice also, there doesn't appear to be a La Niña event after the 1982/83 El Niño using the Southern Oscillation index, but one is present in the NINO3.4 data. Other than those and some others minor differences, the two datasets do mimic one another, but inversely.

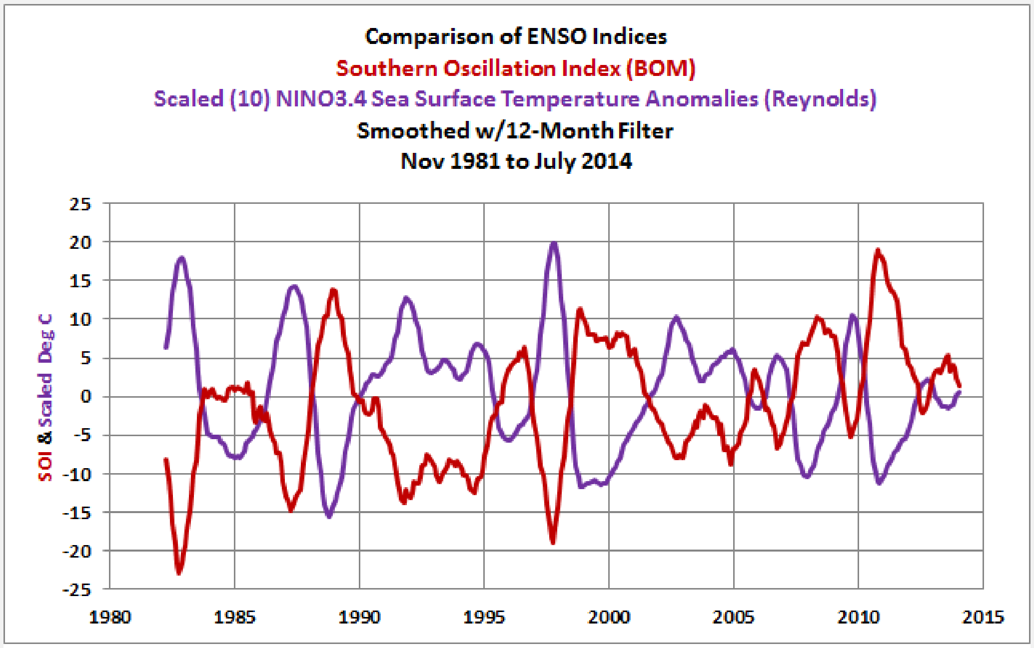


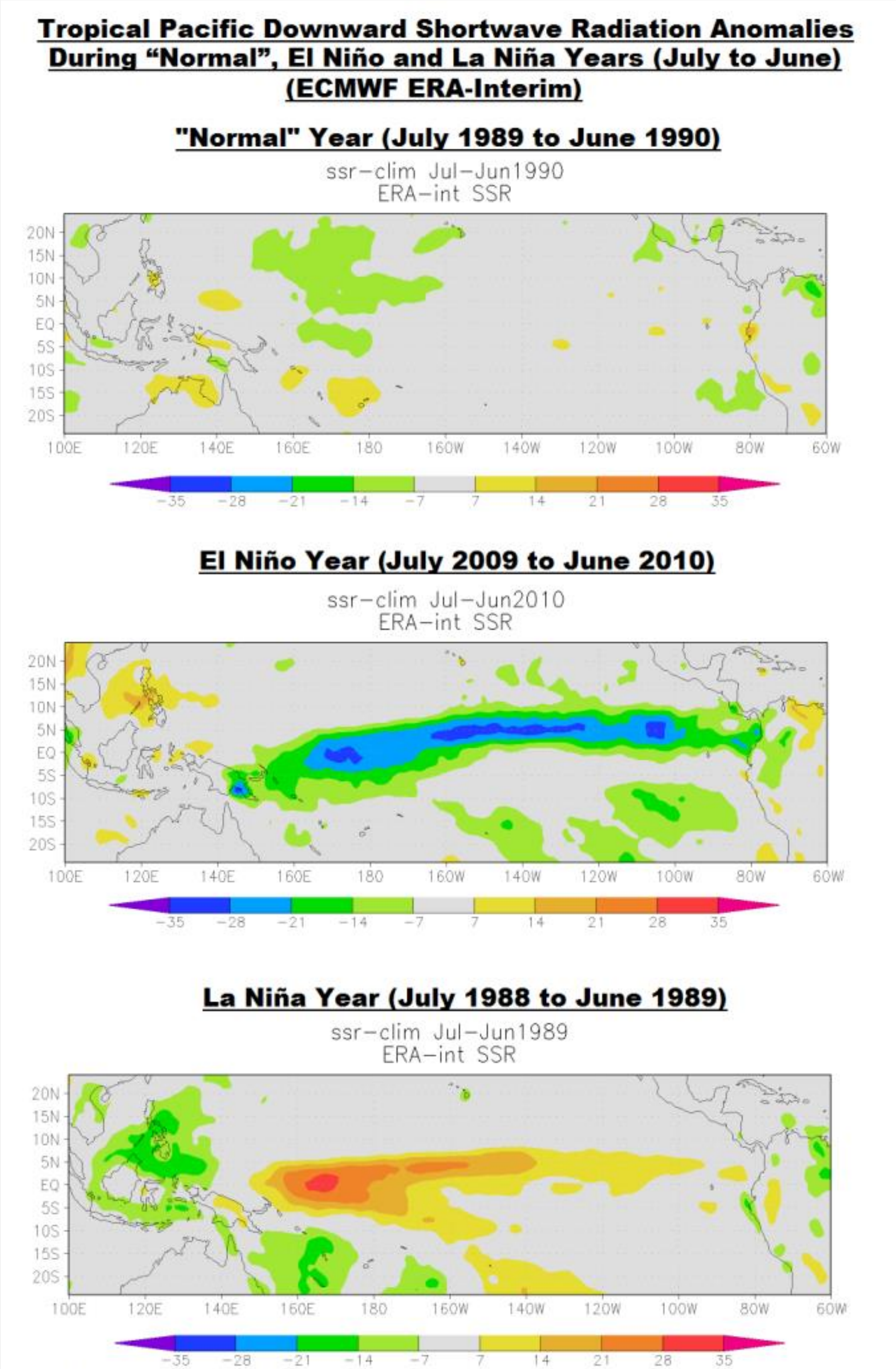
Figure 3.7-15

According to the BOM, La Niña events are sustained positive Southern Oscillation Index values in excess of +8 and El Niño events are sustained negative values in excess of -8. In that discussion at the BOM website, however, the Southern Oscillation Index data is being presented as a 30-day running average, so you can't apply those values to Figure 3.7-15, which has been smoothed with a 12-month running-average filter.

HOW IS THE WARM WATER FOR AN EL NIÑO CREATED?

The quick answer: the warm water for an El Niño event is typically created during a preceding La Niña event. Cloud amounts over the tropical Pacific decrease during a La Niña. The reduction in cloud cover allows more sunlight than normal to heat the surface and subsurface waters of the tropical Pacific. That warm water is carried west by trade wind-driven ocean currents and it collects in the western tropical Pacific.

Figure 3.7-16 presents maps of downward shortwave radiation (visible sunlight) anomalies at the surface of the tropical Pacific for an ENSO-neutral (normal) year, an El Niño year and a La Niña year. Because there are few actual measurements of downward shortwave radiation at the surface for the tropical Pacific, we have to rely on the output of a reanalysis, which as we've discussed many times is a model that uses data (such as cloud cover) as inputs. That reanalysis is the ECMWF (European Centre for Medium-Range Weather Forecasts) ORA-Interim Reanalysis.



Maps Created at KNMI Climate Explorer

Figure 3.7-16

The top cell, the "normal" year (July to June) shows a few weather-related anomalies of sunlight reaching the surface. During the El Niño year, the center cell, there were enormous declines in sunlight reaching the surface. That, of course, is a response to the warmer waters, which cause more evaporation, convection and cloud cover. The greater the cloud cover, the lower the amount of sunlight reaching the surface. Or to look at the El Niño in another light, sunlight to the tropical Pacific decreases during an El Niño in response to the release of heat from the ocean to the atmosphere. The bottom cell captures the increased amount of sunlight reaching the surface of the tropical Pacific during the La Niña year. Note the scaling of the color coding. In the portion that's bright red along the equator at about 165E longitude, the peak average sunlight for that 12-month period was between 28 to 35 watts/m^2 above normal. The burnt orange region (from about 155E to the dateline) received 21 to 28 watts/m^2 more sunlight for that year. Those are tremendous temporary increases in the amount of sunlight reaching the surface of the western equatorial Pacific, which is why I often refer to them as "blasts of sunlight" during La Niñas. That is a response to the cooler surface waters, which cause less evaporation, convection and cloud cover. Less cloud cover yields more sunlight. All of that sunlight warms the water at the surface and below the surface, and that sunlight-warmed water is carried west to the Pacific Warm Pool.

We have two quotes from papers by Dr. Kevin Trenberth of NCAR that also support our understanding of how warm water is created for El Niños. The first is from Trenberth et al. (2002) Evolution of El Niño-Southern Oscillation and global atmospheric surface temperatures. They write (my boldface):

> *The negative feedback between SST and surface fluxes can be interpreted as showing the importance of the discharge of heat during El Niño events and of the recharge of heat during La Niña events. Relatively clear skies in the central and eastern tropical Pacific allow* ***solar radiation to enter the ocean****, apparently offsetting the below normal SSTs, but the heat is carried away by Ekman drift, ocean currents, and adjustments through ocean Rossby and Kelvin waves, and the heat is stored in the western Pacific tropics. This is not simply a rearrangement of the ocean heat, but also a restoration of heat in the ocean.*

Dr. Trenberth just described ENSO as a basic recharge-discharge oscillator, where the recharge takes place during the La Niña and the discharge takes place during the El Niño.

The second paper is Trenberth and Fasullo (2011) Tracking Earth's Energy: From El Niño to Global Warming. They write (my boldface):

> *Typically prior to an El Niño, in La Niña conditions, the cold sea waters in the central and eastern tropical Pacific create high atmospheric pressure and clear*

> *skies, **with plentiful sunshine heating the ocean waters**. The ocean currents redistribute the ocean heat which builds up in the tropical western Pacific Warm Pool until an El Niño provides relief (Trenberth et al. 2002).*

Trenberth and Fasullo again described a basic recharge-discharge mechanism.

Let's discuss this a little more, because it is important that readers understand that it is sunlight that provides the fuel for El Niño events, and that the fuel is created during La Niña events.

Pavlakis et al (2008) ENSO surface shortwave radiation forcing over the tropical Pacific is a study of the relationship between sunlight in the tropical Pacific and El Niño and La Niña events. Their abstract begins:

> *We have studied the spatial and temporal variation of the downward shortwave radiation (DSR) at the surface of the Earth during ENSO events for a 21-year period over the tropical and subtropical Pacific Ocean (40S–40N, 90E–75W). The fluxes were computed using a deterministic model for atmospheric radiation transfer, along with satellite data from the ISCCP-D2 database, reanalysis data from NCEP/NCAR for the key atmospheric and surface input parameters, and aerosol parameters from GADS (acronyms explained in main text). A clear anti-correlation was found between the downward shortwave radiation anomaly (DSR-A) time-series, in the region 7S– 5 N, 160 E-160W located west of the Niño-3.4 region, and the Niño-3.4 index timeseries. In this region where the highest in absolute value DSR anomalies are observed, the mean DSR anomaly values range from −45Wm−2 during El Niño episodes to +40Wm−2 during La Niña events.*

So according to Pavlakis et al. (2008) sunlight reaching the surface of the west-central region of the equatorial Pacific can drop as much as 45 watts/m^2 during an El Niño when the tropical Pacific is discharging heat and increase as much as 40 watts/m^2 during a La Niña when the tropical Pacific is recharging the heat.

My Figure 3.7-17 is Figure 6 from Pavlakis et al (2008). It clearly shows an inverse relationship between sunlight for two regions of the equatorial Pacific and the sea surface temperatures of the NINO3.4 region.

Again, sunlight reaching the tropical Pacific decreases when El Niños are releasing heat from the tropical Pacific and sunlight increases when La Niñas are recharging the heat for the next El Niño.

Figure 6 from Pavlakis et al (2008) "ENSO Surface Shortwave Radiation Forcing over the Tropical Pacific"

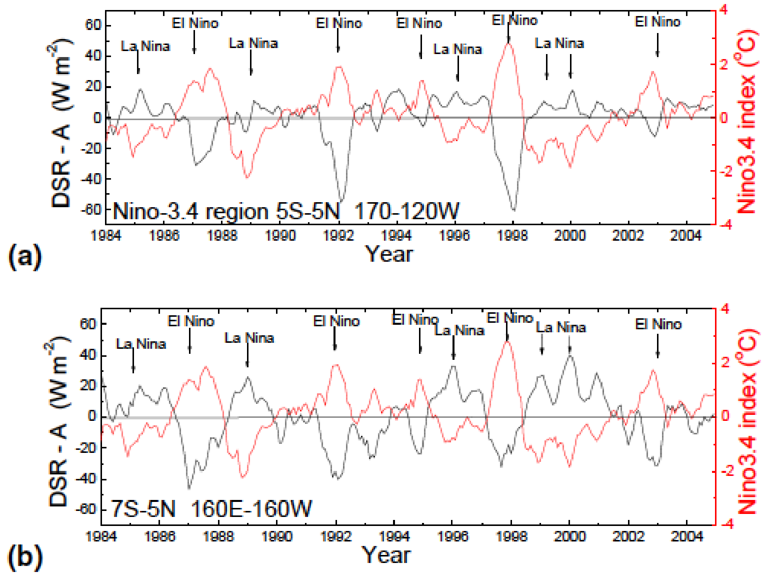


Fig. 6. Time-series of downward shortwave radiation anomaly (DSR-A) at the surface (defined with respect to the average monthly DSR for the whole study period 1984–2004) in the Niño-3.4 region **(a)**, and in the central Pacific region (7° S–5° N 160° E–160° W) **(b)**. Overlaid is the time-series of the Niño-3.4 index (red line).

Figure 3.7-17

Note: Pavlakis et al. (2006) ENSO surface longwave radiation forcing over the tropical Pacific is the sister paper to Pavlakis et al (2008), but in their 2006 paper, Pavlakis and others are discussing the impacts of El Niño and La Niña events on downward longwave radiation (infrared radiation).

I've included Figure 7 from Pavlakis et al. (2006) as my Figure 3.7-18. It shows the direct relationship between El Niño and La Nina events and the resulting variations in infrared radiation reaching the west-central and east-central equatorial Pacific. The following two sentences are important, so I've isolated them and underlined them.

During La Niña events, infrared radiation decreases over the equatorial Pacific, so infrared radiation does not provide the energy to recharge the tropical Pacific during La Niña events. That logically leaves sunlight as the source of fuel for El Niño events.

Figure 7 from Pavlakis et al (2006) "ENSO Surface Longwave Radiation Forcing Over the Tropical Pacific"

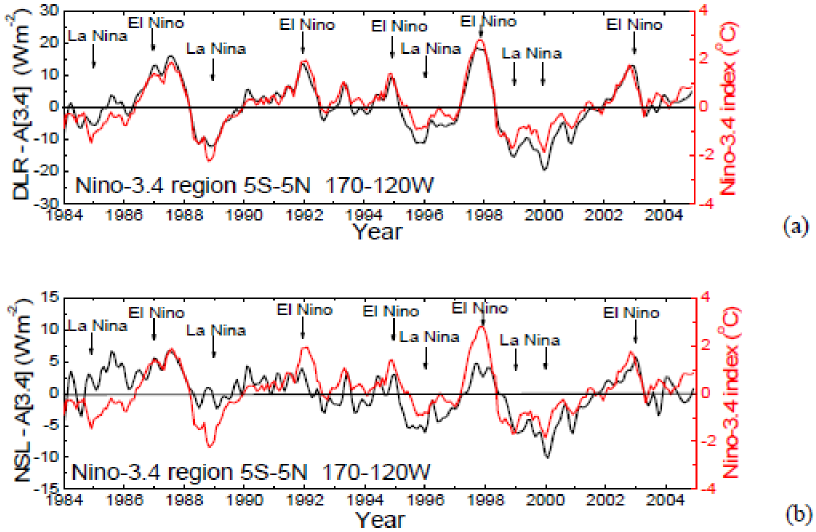


Fig. 7. Time-series of downward longwave radiation (DLR-A[3.4]), and net surface longwave radiation (NSL-A[3.4]) anomaly (defined with respect to the average monthly DLR for the whole study period 1984–2004) in the Niño-3.4 region (black line). Overlaid is the time-series of the Niño-3.4 index (red line).

Figure 3.7-18

You might be saying to yourself, but infrared radiation reaching the surface of the tropical Pacific increases during El Niños. Yes, that's right, but the tropical Pacific is releasing heat during El Niños, not replenishing it.

OCEAN HEAT CONTENT DATA FOR THE TROPICAL PACIFIC CONFIRMS THAT EL NIÑOS DISCHARGE HEAT AND THAT LA NIÑAS RECHARGE IT

The National Oceanographic Data Center (NODC) has created a number of datasets based on subsurface temperature and salinity observations of the global oceans. Sampling, globally, was very poor—almost nonexistent in the Southern Hemisphere—before the ARGO floats were deployed in the early 2000s. A number of buoys, however, anchored to the ocean floor, have been in place in the tropical Pacific since the early 1990s. Those fixed buoys were installed as part of the NOAA Tropical Atmosphere-Ocean (TAO) Project. Installation began in the 1980s and it was complete in the early 1990s. So from the early 1990s to present, the NODC ocean heat content data for the tropical Pacific should be reasonable. Prior to the early 1990s, the data are questionable. We can find major changes in the earlier data, but the annual variations due to individual El Niños and La Niñas don't make their presence as well known.

Figure 3.7-19 presents the NODC ocean heat content data for the tropical Pacific (24S-24N, 120E-80W), for the depths of 0-700 meters (about 0-2300 feet). As illustrated earlier in this chapter, the vast majority in the subsurface temperature changes along the equatorial Pacific take place in the top 300 meters (almost 1000 feet), so the depth range of 0-700 meters (about 0-2300 feet) captures those variations. While El Niño and La Niña events are focused on the equatorial Pacific, they have direct impacts on the tropical Pacific as a whole, so we're looking at the ocean heat content for the entire tropical Pacific in this example.

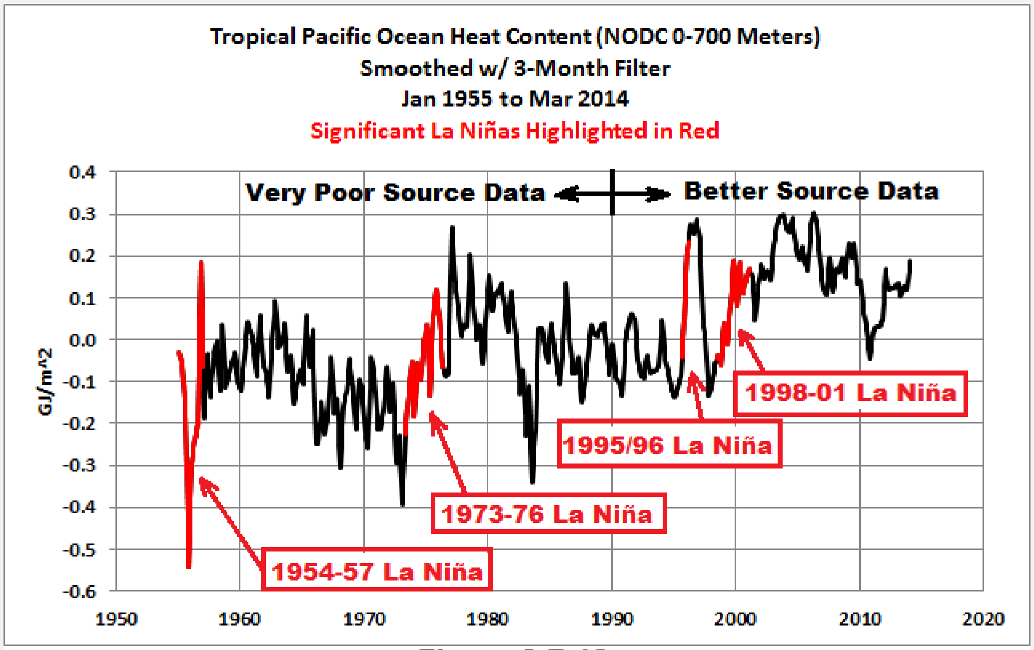


Figure 3.7-19

I've also highlighted the significant La Niña events on the graph…significant in terms of ocean heat uptake for the tropical Pacific. The "official" months of those La Niña events are as listed in the NOAA Oceanic NINO Index (ONI). The dataset starts during a 3-year La Niña, but there's very little source data then so the extent of the variations at that time are very questionable. But we can see the ocean heat content of the tropical Pacific dropped from the late 1950s to the early 1970s. Then, the 1973-76 La Niña replenished and added to the warm water in the tropical Pacific. After that multiyear La Niña, the tropical Pacific cooled once again, not warmed, until the early-1990s. Then, according to the ocean heat content data for the tropical Pacific, something remarkable happened in 1995/96. The relatively mild La Niña event of 1995/96 (mild in terms of surface-related ENSO indices) caused a massive increase in the ocean heat content of the tropical Pacific. With the help of the 1998-01 La Niña, the 1995/96 La Niña effectively shifted up the ocean heat content of the tropical Pacific. Note the drop in ocean heat content between the 1995/96 and 1998-01 La Niñas. That drop was caused by the monumental release of heat and warm water from the tropical Pacific as a result of the 1997/98 "super El Niño". In other words, all of the warm water for the 1997/98 El Niño was created during the 1995/96 La Niña.

TRENBERTH'S BIG JUMPS

OR

HOW STRONG EL NIÑOS CAUSE A LONG-TERM INCREASE IN GLOBAL SURFACE TEMPERATURE

OR

MORE INFO ON THE TRENBERTH STAIRCASE

In the Introduction, we noted that Dr. Kevin Trenberth, of the National Center for Atmospheric Research presented how global surface temperatures warmed in steps in his May 2013 Royal Meteorological Society (RMS) article titled Has Global Warming Stalled? And I presented Figure 3.7-20 to show to show that stair-like effect.

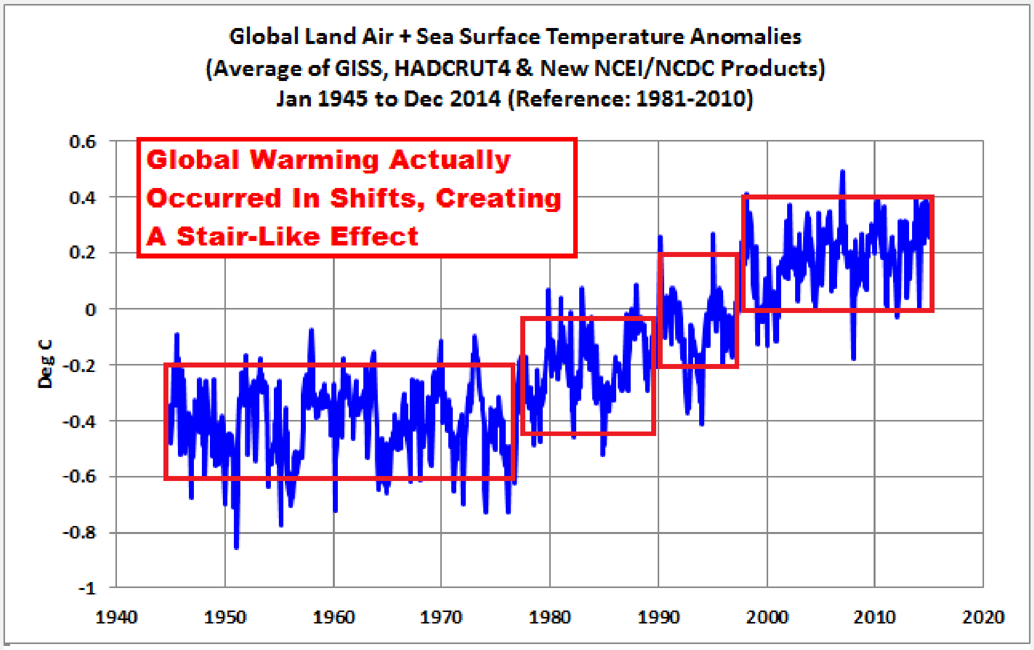


Figure 3.7-20

And as I noted in the Introduction, Dr. Trenberth was trying to downplay the significance of the recent slowdown or halt in the warming of global surface temperatures—a.k.a. the hiatus or pause—in his article for the Royal Meteorological Society. He noted that decadal periods of no warming were commonplace and that global surface temperatures actually warmed in "big jumps" with decade-long hiatus periods in between. Dr. Trenberth failed to present the causes of those "big jumps" in that article, but in later interviews, Dr. Trenberth admitted that El Niño events were the cause of the jumps in global surface temperatures.

Kevin Trenberth discussed the stair-like increases in global surface temperature in an interview with Peter Sinclair of ClimateCrocks. The interview (presented in two YouTube videos) was about Trenberth's thoughts on the impacts of a strong El Niño event, back when it was thought there would be a strong El Nino forming in 2014. See Part 1 here. At about the 9-minute mark in Part 2 (here), Trenberth speculates, sounding positively overjoyed, that the upcoming El Niño may lead to another in the series of upward steps in global surface temperature:

> *One of the real prospects to look out for is whether we go back into a different phase of this Pacific Decadal Oscillation. And one of the potential prospects we can watch out for is whether the next whole decade will be distinctly warmer…uh, uh…and so, in terms of the global mean temperature, instead of having a gradual trend going up, maybe the way to think of it is we have a series of steps, like a staircase. And, and, it's possible, that we're approaching one of those steps. And we will go up, you know, two- or three-tenths of a degree Celsius to a next level, and maybe we won't come down again. I think that's one of the things we could possibly look out for.*

There are a number of additional recent interviews where Trenberth refers to El Niño-caused "big jumps" in global surface temperatures, from which we never come down again. One example is his August 2013 interview on National Public Radio (NPR). There he is reported to have said:

> *…what happens at the end of these hiatus periods, is suddenly there's a big jump [in temperature] up to a whole new level and* ***you never go back to that previous level again****…*

Curiously, Trenberth has never taken the time to explain that we would NOT expect the surface temperatures to go back down again. The Earth has simply entered a new warmer climate state, one which was caused by the long-term effects of a strong El Niño. So I'm baffled by the intent of his "never go back to that previous level again". Because Trenberth has been associated with the IPCC, and because he's been such a strong campaigner for the hypothesis of human-induced global warming, everyone assumes that somehow this "never go back to that previous level again" is associated with man-made global warming…when, in fact, an El Niño is part of a naturally occurring and naturally fueled process.

Naturally fueled: we've already presented how Dr. Trenberth has noted in two scientific papers that El Niño events are fueled by sunlight. Refer to the discussion under the previous heading of HOW IS THE WARM WATER FOR AN EL NIÑO CREATED?

There are a number of mechanisms through which a strong El Niño can and does cause a long-term increase in global surface temperatures.

A strong El Niño releases an immense amount of warm water from below the surface of the western tropical Pacific and places much of that warm water on the surface. At the end of the El Niño, that warm water (that's now on the surface) is redistributed to adjoining ocean basins. There is so much leftover warm water on the surface after a strong El Niño that the surface temperatures of those oceans shift upwards.

To phrase that a little differently, before the strong El Niño, a large pool of warm water is located below the surface of the western tropical Pacific. While it's below the surface, it is excluded from the surface temperature record. During the El Niño, those warm subsurface waters flood into the eastern tropical Pacific, and much of it is upwelled to the surface. The warm water is now included in the surface temperature record. At the end of the El Niño, the restored trade winds push all of the leftover warm water—still on the surface and still included in the surface temperature record—back to the western tropical Pacific where it is distributed poleward within the Pacific and distributed into the tropical Indian Ocean.

Sea surface temperature data show evidence of this leftover warm water.

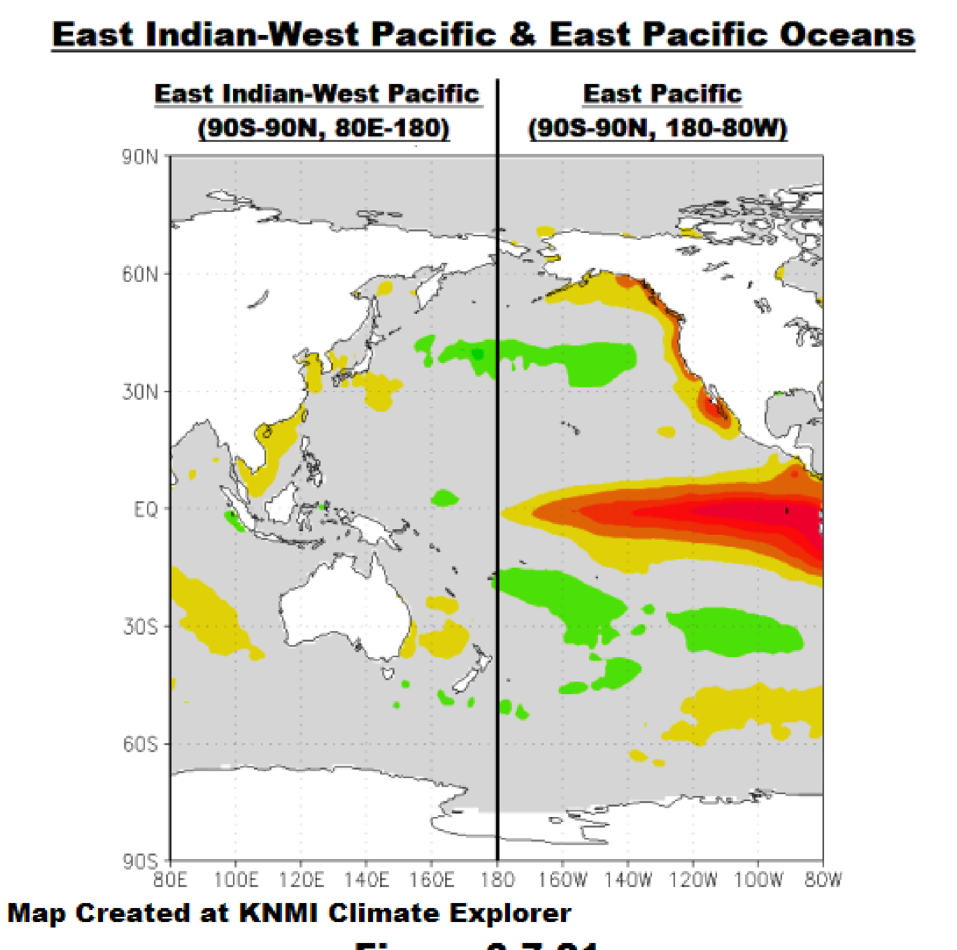


Figure 3.7-21

Let's look at the satellite-enhanced sea surface temperature data for two regions: the East Pacific and the East Indian-West Pacific. For these discussions, the data also extend into the Arctic and Southern Oceans. See the map above in Figure 3.7-21. We can see an El Niño taking place in the eastern tropical Pacific. That's the 1997/98 El Niño, by the way.

Figure 3.7-22 is a time-series graph that presents the satellite-era sea surface temperature anomalies for the East Pacific, based on the Reynolds OI.v2 sea surface temperature data. Also included is the linear trend. The large upward spikes are of course caused by El Niño events. Warm water from below the surface of the West Pacific Warm Pool floods into the eastern tropical Pacific, where it is upwelled to the surface and raises sea surface temperatures. After the El Niño, the warm water is swept back to the west. We can also see the impacts of the additional upwelling of cool subsurface waters during La Niña events, with the extreme dips and rebounds, brought on by the stronger trade winds. All in all, though, there has been very little warming of the surface of the East Pacific Ocean…even with The Blob. Now consider that the East Pacific (90S-90N, 180-80W) covers about 33% of the surface of the global oceans. That is a tremendous portion of the global oceans to show so little warming.

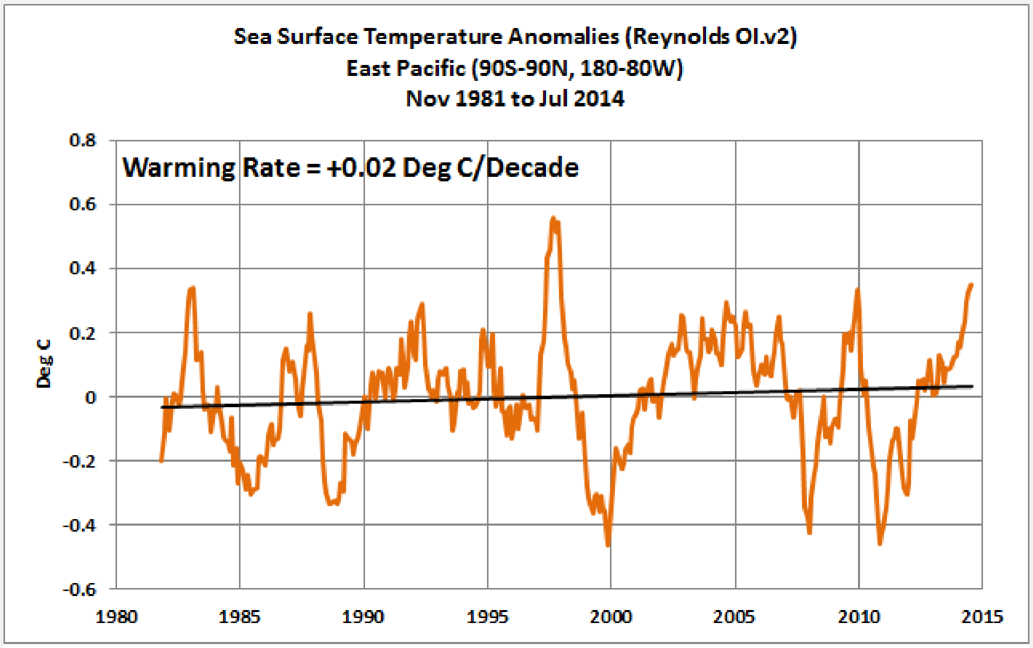


Figure 3.7-22

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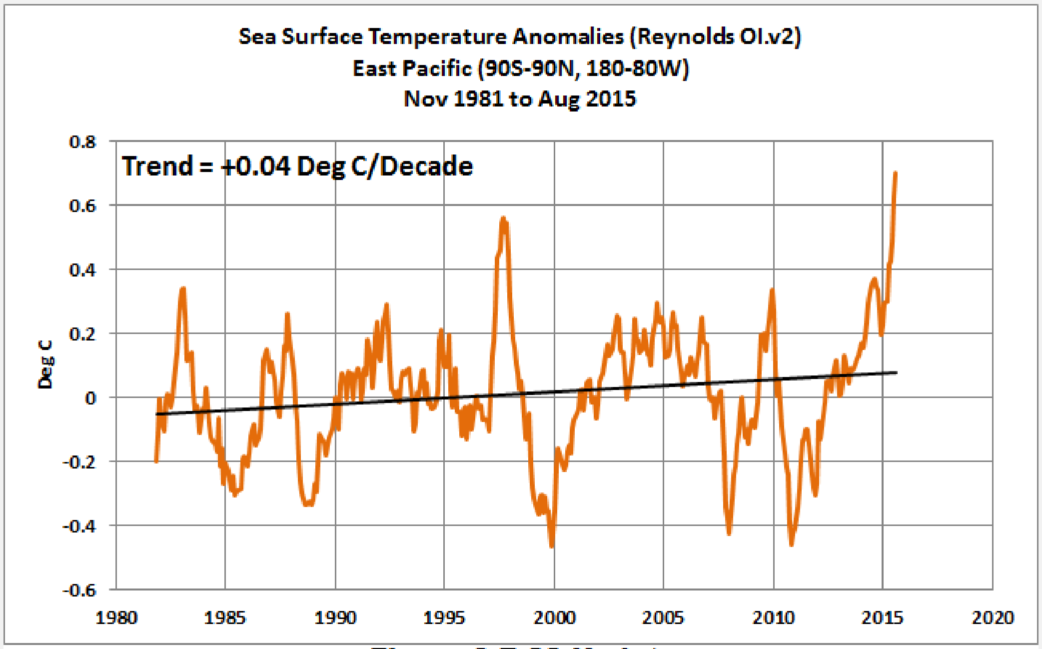

Figure 3.7-22 Update

I've updated Figure 3.7-22 to show the combined impacts on the sea surfaces of the East Pacific of the 2015/16 El Niño and unusual warming event in the eastern extratropical North Pacific called The Blob.

Figure 3.7-23 shows the satellite era sea surface temperature anomalies for the East Indian and West Pacific Oceans, which was the western (left-hand) region shown above in Figure 3.7-21. I've highlighted in red the responses to the strong El Niño events of 1982/83, 1986/87/88, 1997/98 and 2009/10. I used the NOAA Oceanic NINO Index to determine the "official" months of those El Niño and then lagged them 6-months. The lagging was done to account for the delay in the response time of the surface of the East Indian-West Pacific Oceans to those El Niños. There are a few things plainly evident in the graph of the East Indian-West Pacific surface data. First, there is a long-term warming trend. There should be no doubt about that. The second thing: the surfaces of the East Indian-West Pacific warmed in steps in response to the strong El Niños of 1982/83, 1986/87/88, 1997/98 and 2009/10. Contrary to Dr. Trenberth's claim that "we won't come down again", the surfaces of this part of the global oceans do slowly cool after the strong El Niños of 1986/87/88 and 1997/98, but, by the time the next strong El Niño strikes, the surfaces haven't cooled fully to the point they had been at before the original El Niño. Third: the sea surfaces of the East Indian-West Pacific Oceans warm during the strong El Niño events, but do not cool proportionally during the La Niñas that trail them.

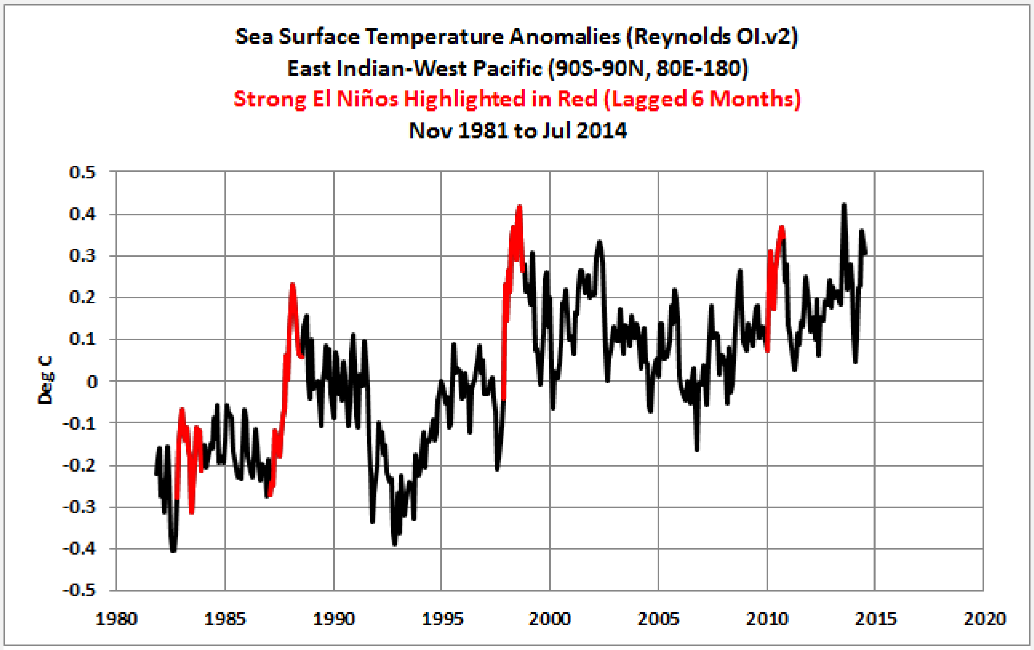

Figure 3.7-23

That is, look at the sea surface temperature data for the East Pacific back in Figure 3.7-22. Prior to 2013 and The Blob, the sea surface temperature anomalies rise well above zero during an El Niño and fall well below zero during a La Niña. But that doesn't happen in the East Indian-West Pacific subset. That's important, and the cause of this is the warm water that's left over from the strong El Niños. All of that leftover warm water has to go somewhere and it prevents the surface of the East Indian-West Pacific Oceans from cooling proportionally during the trailing La Niña events. So the bottom line: there are stair-like increases in surface temperatures of the East Indian-West Pacific Oceans in response to the leftover warm water from strong El Niños.

Those stair-like increases in surface temperatures are much easier to see in Figure 3.7-24. I've added the blue horizontal lines, which are the averages of the sea surface temperature anomalies for the East Indian-West Pacific subset between the strong El Niños (shown in red). I've added the note to the bottom of the graph to assure readers that the horizontal lines are not trend lines. (There has been confusion in the past.)

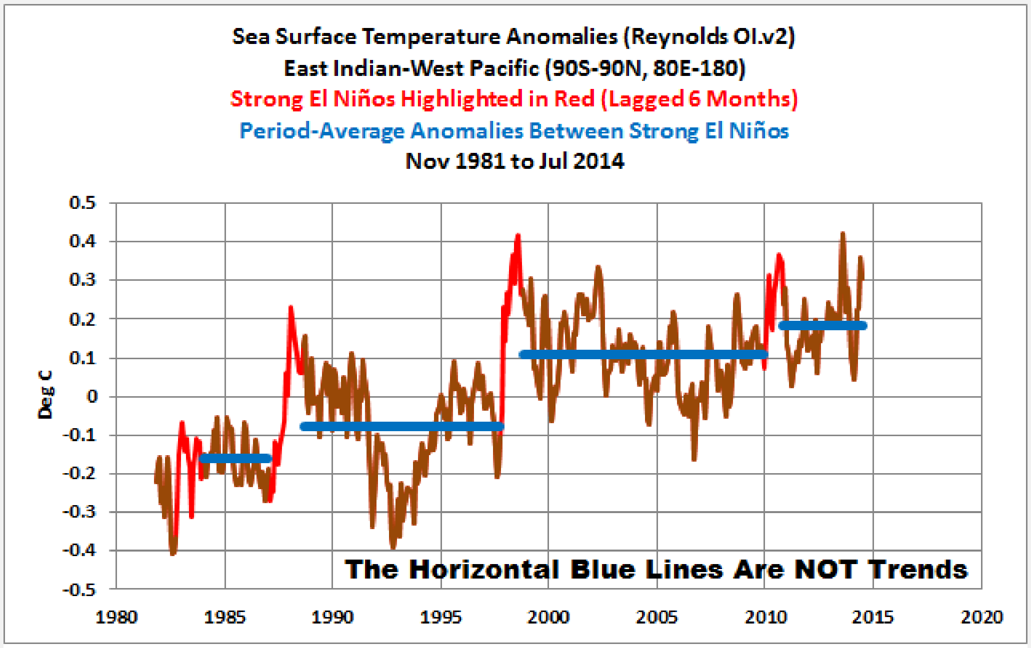

Figure 3.7-24

Note: This is a discussion of the aftereffects of El Niño events. I have not provided updates for Figure 3.7-23, 3.7-24 and many of the following graphs under this heading, because the sea surface temperatures in the regions outside of the East Pacific have not yet responded to the 2015/16 El Niño. I'll confirm this in a few moments. If the sea surfaces of the East Indian-West Pacific and other regions are going to make an upward step in response to the current El Niño, it will start in a few months. [End note.]

The first thing global warming advocates say when they see that graph, or a similar one, is that the graph shows El Niño, La Niña and volcano signals on top of a man-made global warming-caused warming trend. Their beliefs blind them from looking at data and interpreting it any other way. We'll show the errors in their logic in a few moments, but, I want to continue on with this presentation.

Let's expand our view of the global oceans to include the South Atlantic, all of the Indian Ocean and the West Pacific. See Figure 3.7-25. The data are a weighted average of two subsets: the North Indian Ocean and Western North Pacific (plus a portion of the Arctic Ocean) at 27.9% and the South Atlantic, South Indian and Western South Pacific (plus a large portion of the Southern Ocean) at 72.1%.

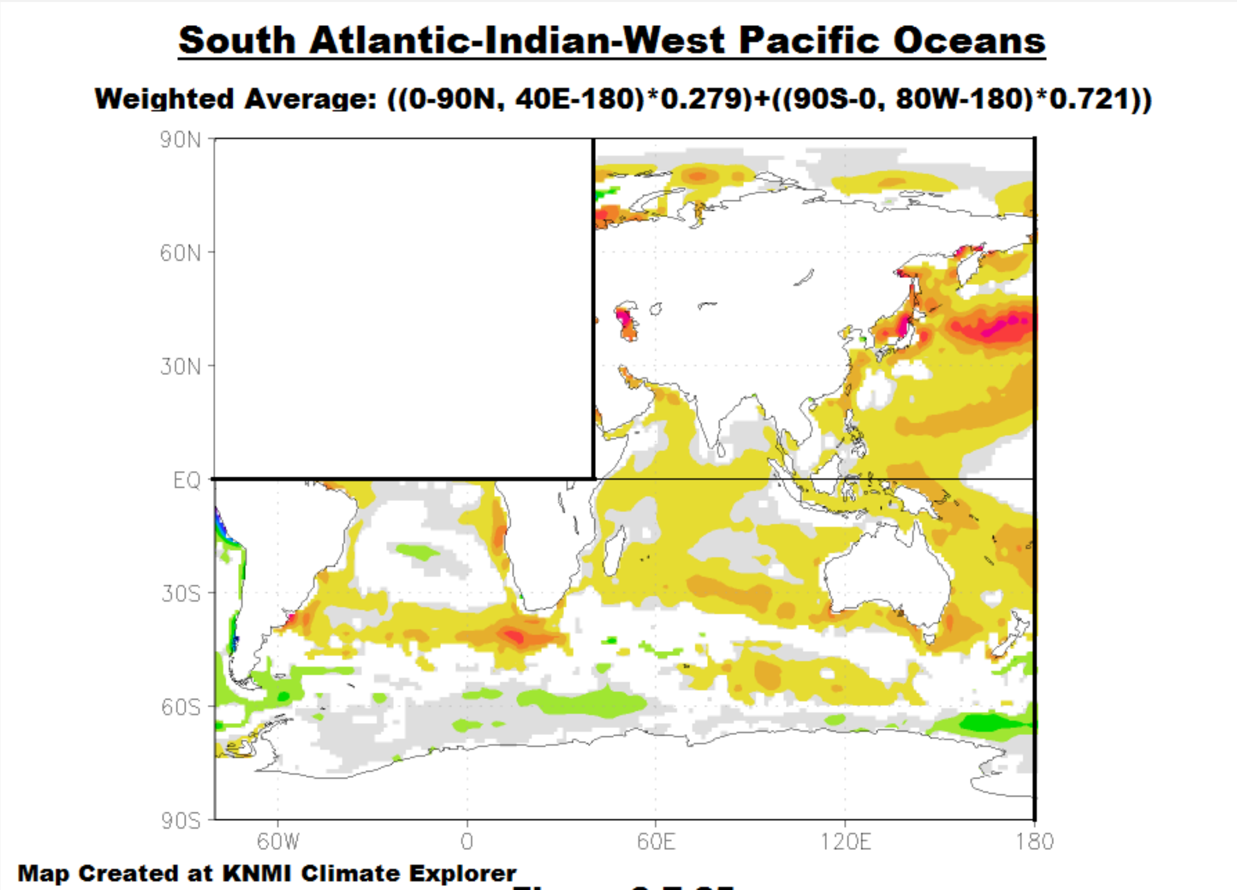

Figure 3.7-25

In Figure 3.7-26, I've presented the sea surface temperature anomalies for the South Atlantic, Indian and West Pacific Oceans with the strong El Niños highlighted in red and with the period-average values of the data between the strong El Niños shown as horizontal blue lines. The satellite-era sea surface temperature data for the South Atlantic, Indian and West Pacific Oceans show similar upward steps. But the cooling is obviously not as drastic between the strong El Niños as it was for the East Indian-West Pacific data, as shown above in Figure 3.7-24. This suggests that some of the cooling taking place in the East Indian-West Pacific subset is caused by the redistribution of the El Niño residual warm water to the South Atlantic and Western Indian Oceans (which were added in Figure 3.7-26.

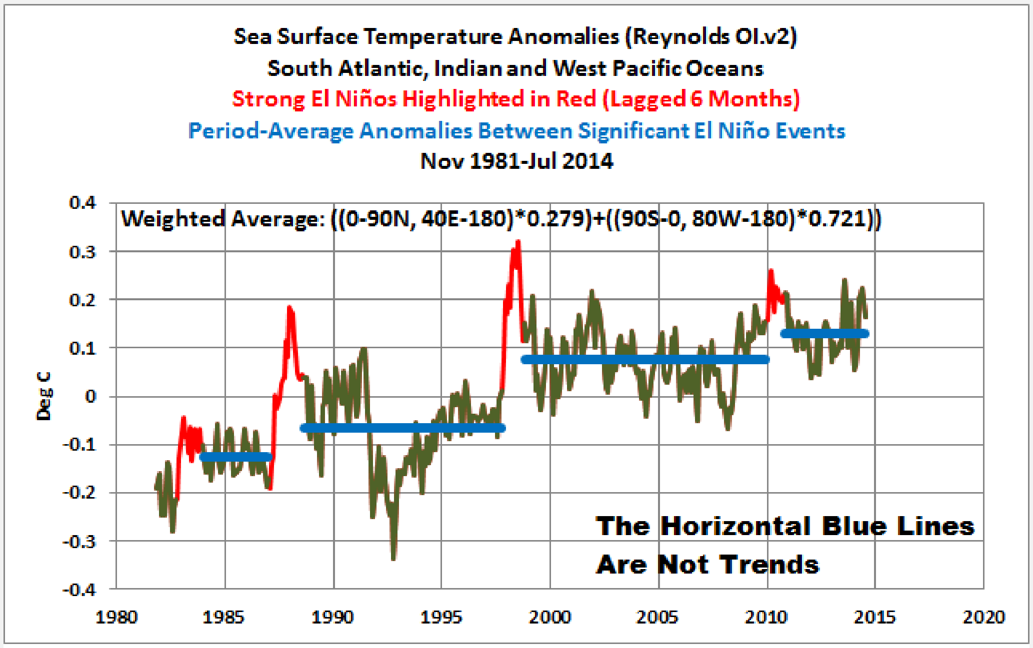

Figure 3.7-26

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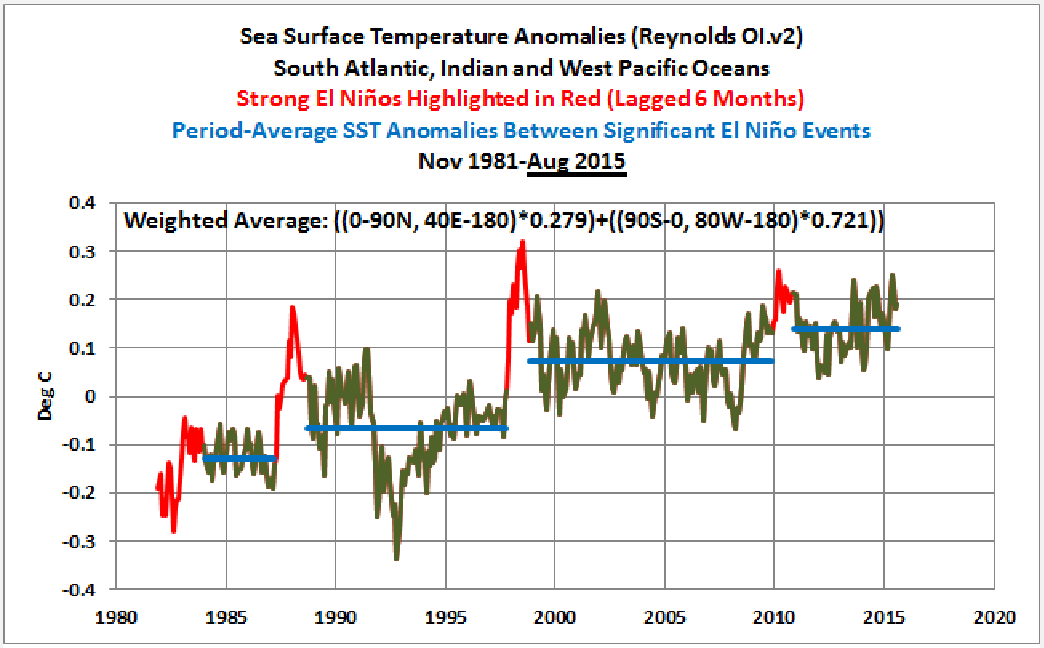


Figure 3.7-26 Update

NOTE: To confirm an earlier note, I've updated Figure 3.7-26 above. The sea surface temperature anomalies for the South Atlantic, Indian and West Pacific Oceans have not yet, as of this writing, responded to the 2015/16 El Niño. If they're going to, and it's likely they will, it will happen soon. [End note.]

Notice again how the surfaces of the South Atlantic, Indian and West Pacific Oceans cool, slightly, after the strong El Niño events of 1986/87/88 and 1997/98. If we add in the North Atlantic, Figure 3.7-27, we can see the same upward steps, except, with the North Atlantic data, the Atlantic, Indian and West Pacific Oceans do not cool noticeably between the strong El Niños. That, of course, results from the naturally occurring high rate of warming taking place (or had been taking place) in the North Atlantic due to the Atlantic Multidecadal Oscillation.

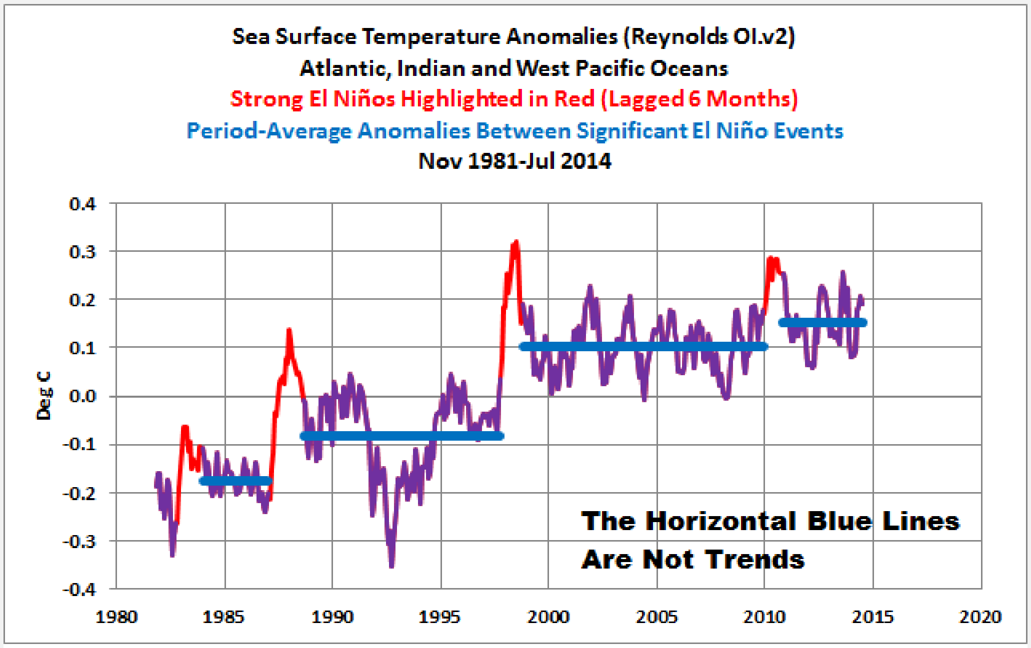


Figure 3.7-27

If you're having trouble seeing the subtle differences between Figures 3.7-26 and 3.7-27, see the gif animation here, which cycles between the two illustrations. When we add the North Atlantic data (Figure 3.7-27), the warming increases (due to the Atlantic Multidecadal Oscillation) and there is less cooling between the strong El Niño events.

Voila! We have shown how and where Dr. Trenberth's stair-like global warming take place and discussed how it originates.

We've already discussed how the North Atlantic has the additional mode of natural variability called the Atlantic Multidecadal Oscillation and that it contributed noticeably to the warming of the surfaces of the Northern Hemisphere and the globe since the mid-1970s. The sunlight-fueled El Niño-caused warming of the surfaces of the South Atlantic, Indian and West Pacific oceans also played a big role in global warming during that period.

How much?

Land surfaces exaggerate and amplify the warming of sea surfaces (through processes known as polar amplification, etc.). It would, therefore, be difficult to say without the use of a climate model. But if we assume that much of the warming of the ocean surfaces results from naturally caused and naturally fueled processes, we could then assume that much of the warming of land surface air temperatures resulted from the natural warming of the oceans. In the paper **Oceanic influences on recent continental warming**, Compo and Sardeshmukh (2009) found that most of the warming on land was a response to the warming of the ocean surfaces. The first sentence of their abstract reads:

> *Evidence is presented that the recent worldwide land warming has occurred largely in response to a worldwide warming of the oceans rather than as a direct response to increasing greenhouse gases (GHGs) over land.*

A QUICK COMPARISON OF THE THREE SUBSETS

As a kind of quick summary, refer to Figure 3.7-28. In it, I've compared the three primary subsets discussed under the last heading:

- The East Pacific [90S-90N, 180-80W]
- The South Atlantic, Indian and West Pacific [A weighted average of ((0-90N, 40E-180)*0.279)+((90S-0, 80W-180)*0.721))]
- The North Atlantic "Plus" (0-90N, 80W-40E)

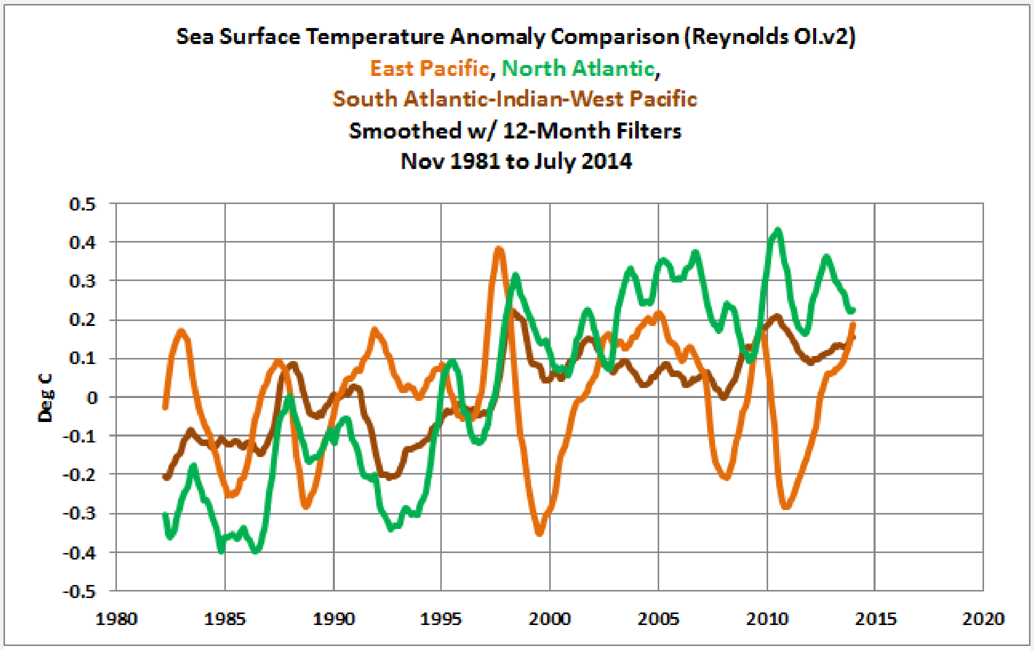


Figure 3.7-28

All three subsets have been smoothed with 12-month running-average filters. The East Pacific (burnt orange curve) shows little to no long-term warming, but there are very large swings caused by El Niño and La Niña events. The South Atlantic, Indian and West Pacific oceans (brown curve) warmed in El Niño-caused upward steps. And the North Atlantic (green curve) had warmed at a higher rate than the other subsets due to the Atlantic Multidecadal Oscillation.

That's a simple explanation for how and where the sea surfaces warmed naturally during the satellite era.

BUT, BUT, BUT…

As noted earlier, proponents of the hypothesis of human-induced global warming look at the "step graphs" presented in Figures 3.7-24, 3.7-26 and 3.7-27 and see something entirely different. They see graphs of man-made global warming with noise from El Niños, La Niñas and volcanic eruptions.

One of the things discussed in the previous section about the step-like responses now comes into play. In Figures 3.7-24, 3.7-26 and 3.7-27, the sea surfaces warm in response to the strong El Niño events but do not cool proportionally during La Niñas that trail them. Proportionally is the operative word in that sentence. We can see that the sea surfaces do cool a little during the La Niñas that trail the strong El Niños, but the cooling during those La Niñas is not proportional to the warming that took place during the strong El Niños. We can confirm that by detrending the relevant subsets. Let's start with the South Atlantic, Indian and West Pacific Oceans. That region covers more than 52% of the surface of the global oceans. See Figure 3.7-29.

For Figure 3.7-29, the Reynolds OI.v2-based sea surface temperature anomalies for the South Atlantic, Indian and West Pacific Oceans have been detrended (dark green curve). There's nothing special about detrending. The recipe for detrending is (1) determine the monthly values of the linear trend line created by the data, and (2) subtract the monthly values of the linear trend line from the monthly values of the data. Figure 3.7-29 also includes NINO3.4 sea surface temperature anomalies (burnt orange curve) that have been scaled, and that means I've simply multiplied the NINO3.4 data by an arbitrary factor (0.1) two bring their variations down into the realm of the other subset. And, of course, we're using the NINO3.4 data as a reference for the timing, strength and length of El Niño and La Niña events. The two subsets have been smoothed with 12-month running-average filters to reduce the weather "noise".

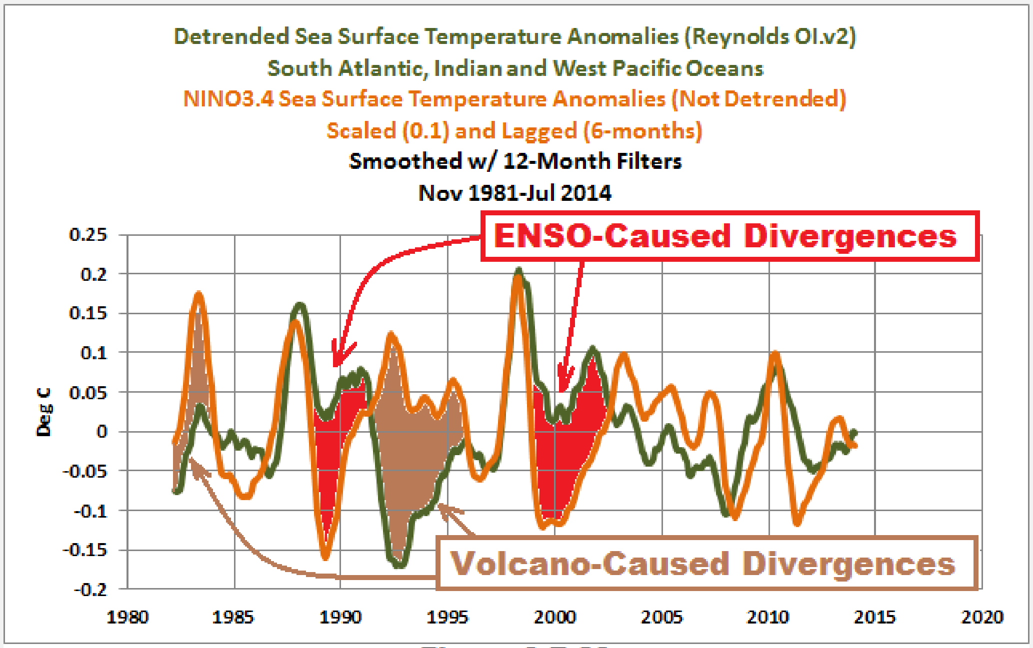


Figure 3.7-29

I've highlighted four times when the detrended data from the South Atlantic, Indian and West Pacific Oceans deviate (diverge) from the NINO3.4 data. Two of the divergences (highlighted in brown) are caused by volcanic eruptions, which impact the sea surface temperature data for the South Atlantic, Indian and West Pacific Oceans but have no noticeable impact on the NINO3.4 data. The other two divergences (highlighted in red) occur during the La Niña events that followed the strong El Niños of 1986/87/88 and 1997/98. It's blatantly obvious that the South Atlantic, Indian and West Pacific Oceans do not cool proportionally during those La Niña events. If they did, the data for the South Atlantic, Indian and West Pacific (the dark green curve) would drop as far as the scaled NINO3.4 data…but they don't. And the reason? There's warm water left over from the strong El Niños that gets distributed into the South Atlantic, Indian and West Pacific Oceans during the trailing La Niñas.

Because the surfaces of the South Atlantic, Indian and West Pacific Oceans do not cool proportionally during the La Niña events of 1988/89 and 1998-01, they warm in what appear to be upward steps. If the surfaces there had cooled proportionally during those La Niñas, then the curve of the South Atlantic, Indian and West Pacific Oceans would resemble the East Pacific data…and it shows little warming over the past 32+ years.

Curiously, the North Atlantic data also show similar divergences during the same La Niñas. See Figure 3.7-30.

I ran through the same process for Figure 3.7-30 as I had for Figure 3.7-29. That is, the North Atlantic sea surface temperature anomalies were detrended. The NINO3.4 data were scaled (this time by a factor of 0.18) and lagged 6 months. And both subsets were smoothed with 12-month running-average filters. Again there are divergences from the two strong volcanic eruptions, and there are divergences during the two La Niñas that follow the two strong El Niños.

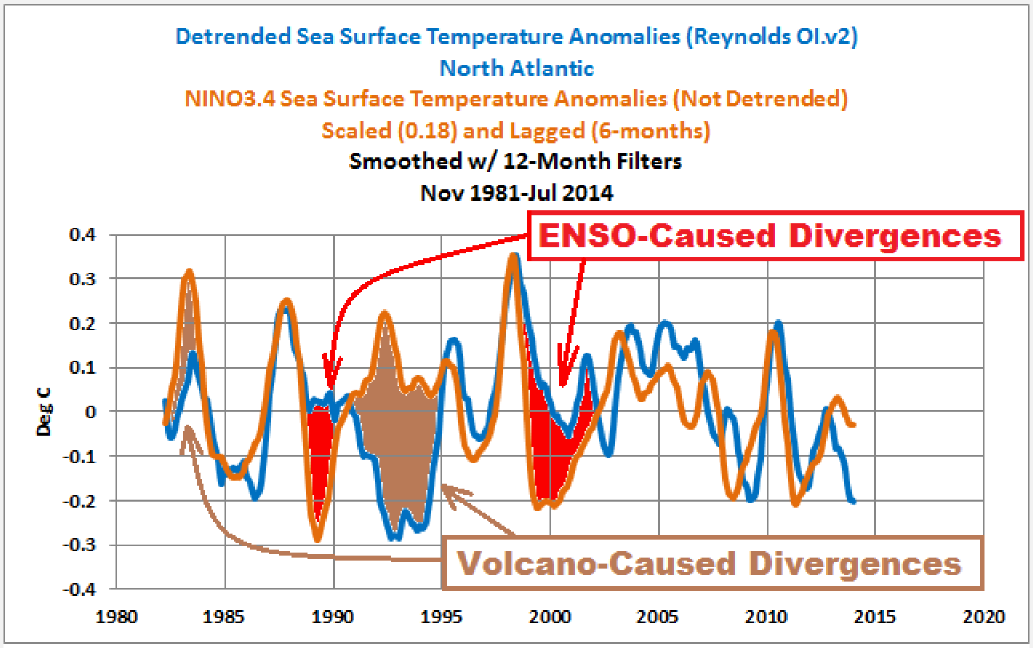


Figure 3.7-30

Now, consider the North Atlantic is isolated from the tropical Pacific. The Americas separate the North Atlantic from the tropical Pacific so the leftovers from the El Niños do not directly impact the sea surface temperatures of the North Atlantic. It's likely the leftover warm water from the strong El Niños causes changes in atmospheric circulation that prevent the North Atlantic from cooling proportionally during the La Niñas that trail them. Unfortunately, there are no scientific studies to confirm this. But we can discuss why the North Atlantic warms in response to El Niño events. That has been studied.

HOW AN EL NIÑO IN THE TROPICAL PACIFIC CAUSES THE NORTH ATLANTIC TO WARM WHEN SEPARATED BY THE AMERICAS

As we can see above in Figure 3.7-30, the North Atlantic clearly warms in response to El Niño events, and while it doesn't cool proportionally during the La Niña events of 1988/89 and 1998-01, it does cool in response to the La Niñas that trail the lesser El Niños. But the Americas separate the North Atlantic from the tropical Pacific and that would make it difficult for the El Niños and La Niñas to have a direct impact on the North Atlantic.

Recall our discussion of the changes in atmospheric circulation along the equator in response to El Niño and La Niña events. (See the heading IMPACTS OF EL NIÑO AND LA NIÑA ON THE ATMOSPHERE.) The North Atlantic warms in response to El Niños (and sometimes cools in response to La Niñas) because of those changes in atmospheric circulation.

That is, those two oceans might be separated by the land mass of the Americas, but the atmosphere above them is not. We already know that the trade winds weaken in the eastern tropical Pacific during an El Niño.

According to Wang (2005) **ENSO, Atlantic Climate Variability, And The Walker And Hadley Circulation**, those changes in atmospheric circulation in the Pacific, in turn, cause the trade winds in the tropical North Atlantic to weaken, too. The slower trade winds blowing across the surface of the tropical North Atlantic Ocean don't cool the surface waters as much as they normally would; there's less evaporation with the weaker trade winds; so the sea surface temperatures warm in the tropical North Atlantic. But that's only part of the explanation from Wang (2005). With trade winds in the North Atlantic at their normal strength, cool waters from below the surface are pulled up to the surface there. In other words, where upwelling occurs in the North Atlantic, it is occurring at its normal rates when the trade winds are at their normal strengths. When the trade winds weaken during an El Niño, there is less cool water being pulled up to the surface, so the tropical North Atlantic warms as a result of that weakening process also. Refer to Wang (2005) for more detailed discussions.

That's the basic explanation of the teleconnection between the sea surface temperatures in eastern tropical Pacific and the sea surface temperatures of the tropical North Atlantic. We'll provide a more general overview of teleconnections in Chapter 3.14 – Teleconnections.

Dr. Kevin Trenberth has written much about ENSO, so he has also discussed the warming of the North Atlantic in response to El Niños. According to Trenberth and Fasullo (2011) Tracking Earth's Energy: From El Niño to Global Warming, an El Niño causes changes in atmospheric circulation that reduce the evaporation from the Atlantic and Indian Oceans and allow more sunlight to penetrate and warm those ocean basins to depth, both of which contribute to the warming of the Atlantic and Indian Oceans in response to an El Niño…without the direct exchange of heat from the tropical Pacific. They write:

> *Meanwhile, maximum warming of the Indian and Atlantic Oceans occurs about 5 months after the El Niño owing to sunny skies and lighter winds (less evaporative cooling), while the convective action is in the Pacific.*

IMPACTS OF ENSO ON OCEAN HEAT CONTENT OF NORTH ATLANTIC AND INDIAN OCEANS

We can also clearly see the impacts of El Niño and La Niña events in the ocean heat content data for the top 700 meters (about 2300 feet) of the entire North Atlantic. Unfortunately, long-term ocean heat content data are lacking, so we have to look at the data only for the ARGO era, starting around 2003. The NODC ocean heat content data (0-700 meters or 0-2300 feet) are available from the KNMI Climate Explorer. In Figure 3.7-31, I've used the coordinates of 0-70N, 80W-0 for the North Atlantic, which are commonly used. And, as a reference for the timing and strengths of El Niño and La Niña events, I've scaled (0.1) NINO3.4 sea surface temperature data, and lagged them 6-months. Clearly, El Niño and La Niña events have strong impacts on the ocean heat content of the North Atlantic.

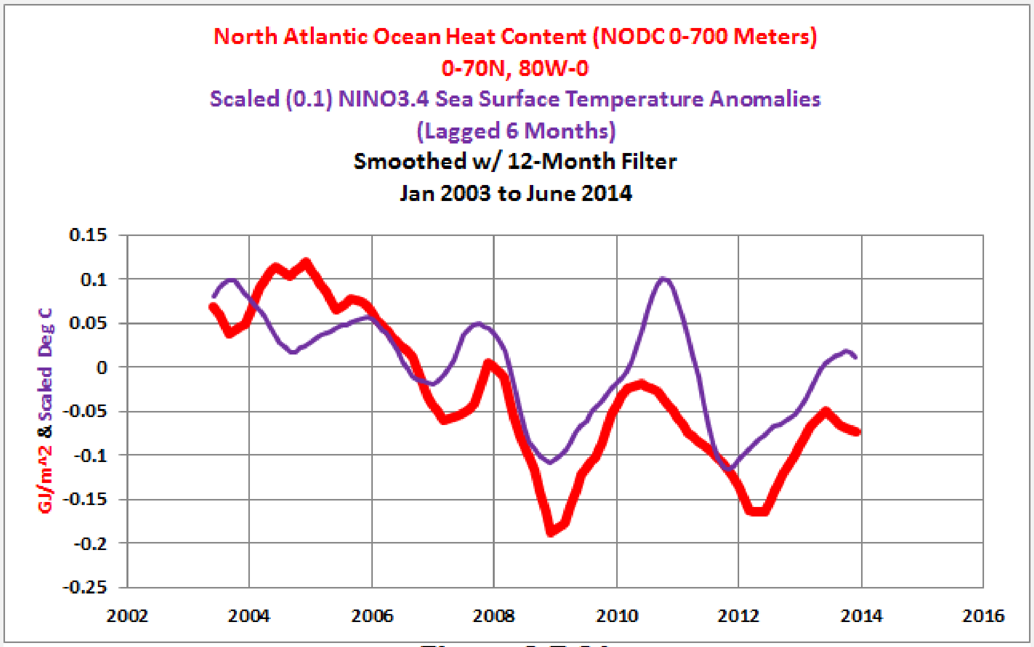


Figure 3.7-31

The impacts of El Niño events on the ocean heat content for the entire Indian Ocean can also be seen, but the Indian Ocean to depths of 700 meters (2300 feet) does not cool proportionally during La Niña events. See Figure 3.7-32 below.

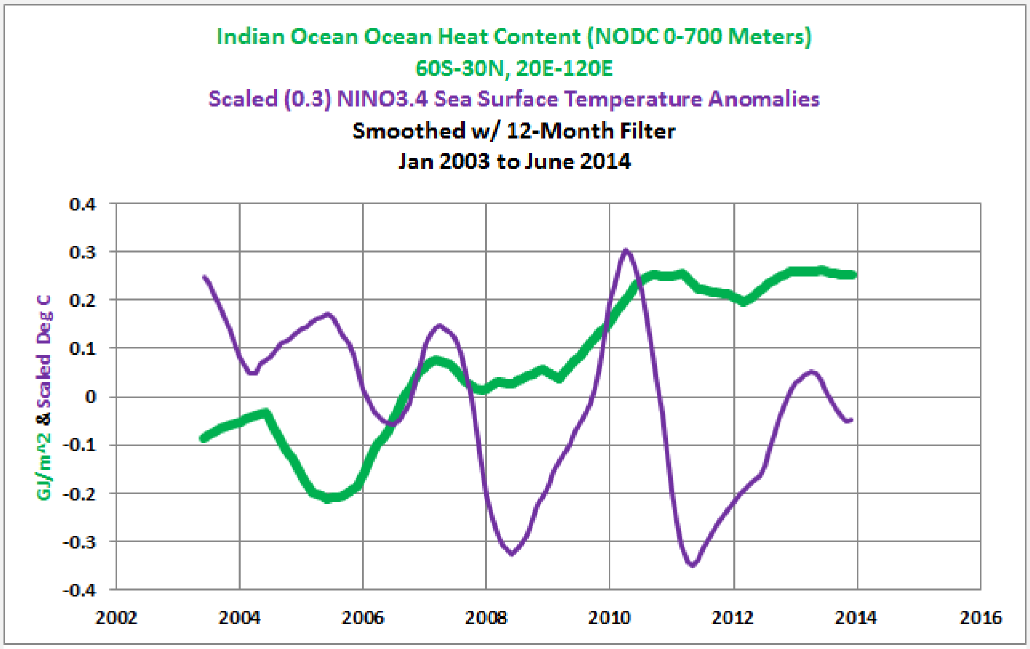


Figure 3.7-32

There is a very likely explanation for this effect, and again it has to do with the warm waters left over from the El Niños. I first presented a graph similar to the one in Figure 3.7-32 as part of the post Is Ocean Heat Content Data All It's Stacked Up to Be? There it was Figure 20. The explanation I provided included two gif animations, which I've linked to the text of the following quote:

> In the following animations, you can watch warm water that's left over from the El Niños being passed from the tropical Pacific into the Indian Ocean during the trailing La Niñas by the current called the Indonesian Throughflow. That leftover warm water counteracts any cooling that would result during the trailing La Niñas due to changes in atmospheric circulation.
>
> Animation 1 presents maps of the NODC ocean heat content data for the ARGO-era, using 12-month averages. The first cells are the average ocean heat content from January to December 2003. These are followed by cells that show the period of February 2003 to January 2004, then March 2003 to February 2004 and so on, until the final cell that captures the average ocean heat content from January to December 2012. The 12-month averages reduce the visual noise and any seasonal component in the data. It's like smoothing data with a 12-month filter in a time-series graph.
>
> Due to the resolution of the ocean heat content data, you might be having trouble catching the processes that cause the leftover warm water from 2006/07 and 2009/10 El Niños to be carried into the Indian Ocean. Animation 2 is a gif animation of sea level maps for the tropical Pacific from the AVISO altimetry

> website. The maps also capture the easternmost portion of the tropical Indian Ocean. I've started the animation in January 2003 to agree with the discussion of ARGO-era ocean heat content data. So there are a couple of minor El Niños before the 2006/07 El Niño. At the end of the 2006/07 El Niño, a (cool) downwelling Kelvin wave splits the elevated (warm) sea level anomalies along the equator. The residual warm waters are carried west by Rossby waves to Indonesia. And the stronger-than-normal trade winds in the Pacific during the trailing La Niña help to force the residual warm water past Indonesia into the eastern Indian Ocean. In addition to the Indonesian Throughflow, warm water from the southern tropical Pacific also migrates west into the eastern Indian Ocean through the Torres Strait, between Australia and New Guinea. The same thing happens after the 2009/10 El Niño. (My apologies for the shift in the animation in 2011. Aviso changed the format of the maps.)

Again, the animations were linked in the body of the quote.

The recent paper Lee et al (2015) Pacific origin of the abrupt increase in Indian Ocean heat content during the warming hiatus confirmed my discussion of the transfer of ENSO-related waters from the tropical Pacific to the Indian Ocean. The abstract reads:

> *Global mean surface warming has stalled since the end of the twentieth century[1, 2], but the net radiation imbalance at the top of the atmosphere continues to suggest an increasingly warming planet. This apparent contradiction has been reconciled by an anomalous heat flux into the ocean[3, 4, 5, 6, 7, 8], induced by a shift towards a La Niña-like state with cold sea surface temperatures in the eastern tropical Pacific over the past decade or so. A significant portion of the heat missing from the atmosphere is therefore expected to be stored in the Pacific Ocean. However, in situ hydrographic records indicate that Pacific Ocean heat content has been decreasing[9]. Here, we analyse observations along with simulations from a global ocean–sea ice model to track the pathway of heat. We find that the enhanced heat uptake by the Pacific Ocean has been compensated by an increased heat transport from the Pacific Ocean to the Indian Ocean, carried by the Indonesian throughflow. As a result, Indian Ocean heat content has increased abruptly, which accounts for more than 70% of the global ocean heat gain in the upper 700 m during the past decade. We conclude that the Indian Ocean has become increasingly important in modulating global climate variability.*

Unfortunately, Lee et al (2015) forgot to consider the increase in downward shortwave radiation we typically see during La Niña events, which fuel El Niños.

LEFTOVER WARM WATERS FROM EL NIÑO EVENTS ALSO EXIST BELOW THE SURFACE

It may not have been obvious in the previous two animations, but much of the warm water that's left over from El Niño events is below the surface. Let's discuss the evolution of an El Niño again.

During the early stages of an El Niño, a westerly wind burst (or series of westerly wind bursts) sends a large pulse of warm water (called a Kelvin wave) eastward along the Pacific Equatorial Undercurrent (a.k.a. Cromwell Current), which carries that warm water below the surface from the West Pacific Warm Pool toward South America. There are two equatorial Kelvin waves visible in the gif animation here at the start of the 1997/98 El Niño. The animation of the Kelvin waves starts in mid-December 1996 to capture the first of two warm (downwelling) Kelvin waves, traveling west to east along the equator. The weaker first Kelvin wave starts at the end of December 1996 and reaches the coast of South America by February 1997. Apparently, it wasn't strong enough to kick off the El Niño. A month later in March 1997, however, the second, much-stronger warm (downwelling) Kelvin waves begins, and it initiated the colossal 1997/98 El Niño.

NOTE: The animation of the Kelvin waves was created from screen captures taken from the JPL animation "tpglobal.mpeg" (which is no longer available from the Jet Propulsion Laboratory's Ocean Surface Topography from Space website). Refer also to the complete JPL animation "tpglobal.mpeg" available on YouTube as full YouTube version of the JPL animation "tpglobal.mpeg". [End note.]

At the end of the El Niño, during the transition from El Niño to La Niña, warm subsurface water that's left over from the El Niño is carried back to the west…all of the way back across the width of the tropical Pacific. That pulse of subsurface warm water traveling from east to west (at about 10N latitude) is called a Rossby wave (sometimes referred to as a slow-moving Rossby wave). And that Rossby wave can be seen in the gif animation here. The impact of the Rossby wave on the sea level of the northwestern tropical Pacific is remarkable. It appears there's a secondary El Niño taking place in the northwestern tropical Pacific while the La Niña is taking place in the east-central equatorial Pacific. It should leave little wonder why the impacts of a La Niña are not always proportional to those of an El Niño.

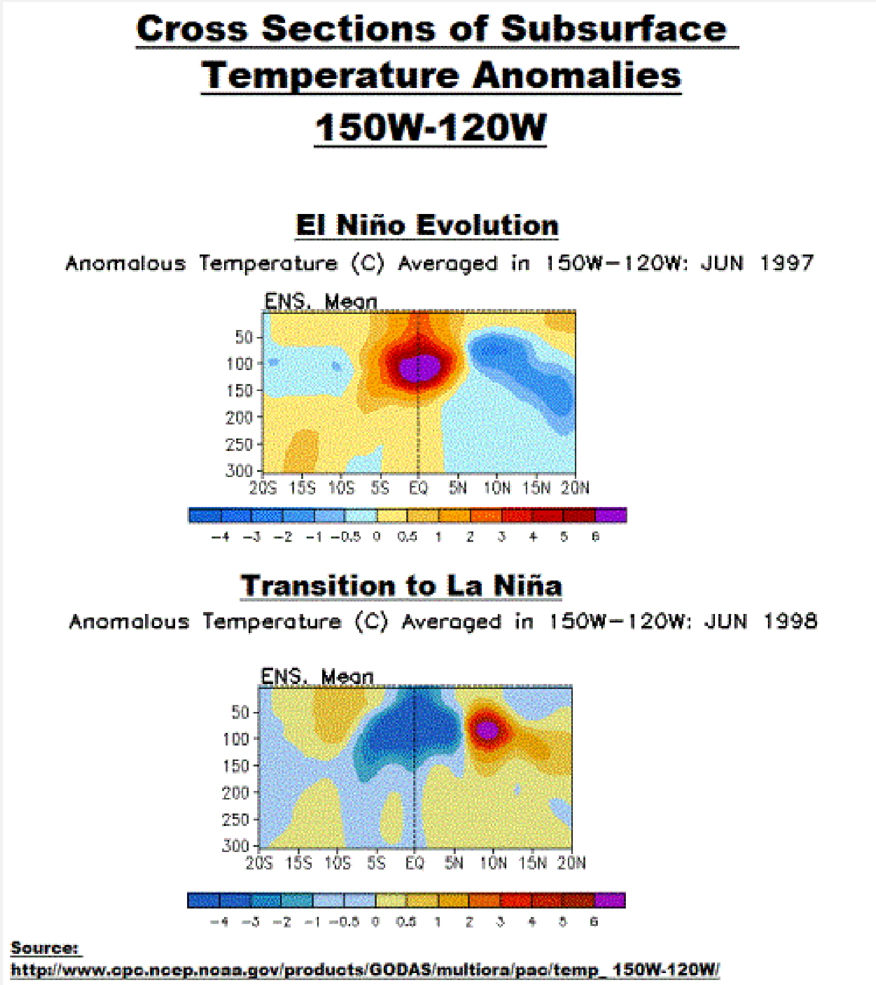


Figure 3.7-33

How deep is that portion of the left over warm water?

There is a NOAA website that collects the ENSO-related reanalyses of the tropical Pacific from a number of sources. (As you'll recall, a reanalysis is the product of a computer model that uses observations-based data as inputs. The reanalysis, in effect, fills in the blanks where no data are available.) And that NOAA website is called the Real Time Multiple Ocean Reanalysis Intercomparison. The website presents images (maps and cross sections) of the El Niño and La Niña temperature anomalies (surface and subsurface of the tropical Pacific) using reanalyses from NCEP, ECMWF , JMA , GFDL , NASA and BOM. Figure 3.7-33 presents cross sections of the subsurface temperature anomalies for a section of the tropical Pacific in June 1997 (El Niño evolution) and in June 1998 (transition from El Niño to La Niña). They are identified at the main webpage as "Temperature anom. in 150W-120W (Y-Z section)". As the viewer, you are facing west looking at these cross sections. The y-axis (vertical-axis) is depth from 0-300 meters (about 0-1000 feet). The x-axis (horizontal-axis) is latitude, with 20S to the left and 20N on the right. The metric is the average temperature anomalies for the longitudes of 150W-120W, which is the east-central portion of the tropical Pacific. (See the map here.) I've only presented the Ensemble Mean (the average of the reanalyses.) For a view of each of the members, see the June 1997 and the June 1998 webpages.

The top cell of Figure 3.7-33 shows the elevated subsurface temperature anomalies below the equator as the Kelvin wave travels from west to east during the evolution of the 1997/98 El Niño. The bottom cell shows the Rossby wave returning the left over warm water from the eastern tropical Pacific to the west.

The pocket of returning warm water resides at depths of 50 to 150 meters (about 165 to 490 feet). With time, the warm water will be carried to the adjoining ocean basins and will rise to the surface. In other words, warm water that was released from below the surface of the West Pacific Warm Pool will transition to the surface and contribute to the long-term global surface warming. That redistribution also contributes to the long-term warming of the subsurface oceans and would, therefore, contribute to the rise in ocean heat that is normally attributed to man-made greenhouse gases.

THE DOMINANCE OF EL NIÑO AND LA NIÑA EVENTS CHANGES WITH TIME

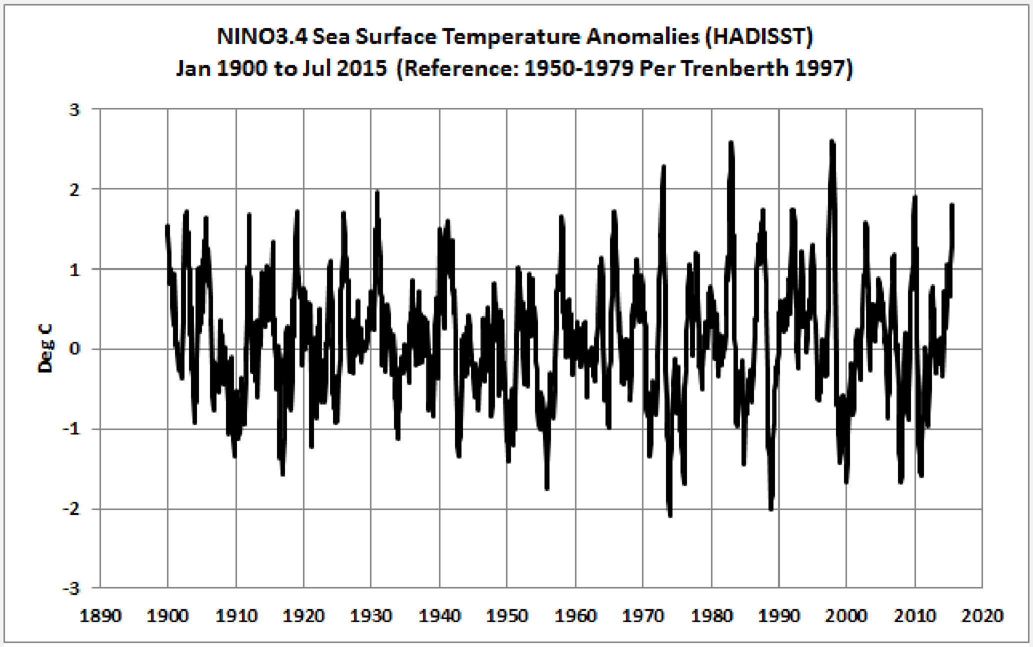


Figure 3.7-34

If we look at a long-term (since 1900) time-series graph of NINO3.4 sea surface temperature anomalies, Figure 3.7-34 (updated through July 2015), we can see that during some decadal and multidecadal periods, El Niños seem to be stronger than La Niñas, and during others, La Niñas appear stronger than El Niños. And both El Niños and La Niñas appear to have temporarily gotten stronger during the 1970s, 80s and 90s.

As a result, the base years used for anomalies can skew the data toward El Niño or La Niña depending on the 30-year period chosen as reference. To avoid any claims that I've cherry picked the base years, I'll refer to the work of Dr. Kevin Trenberth once again. And the paper is Trenberth (1997) The Definition of El Niño. In it, he writes [My boldface and I've added a link to his Figure 1.]:

> *Figure 1 shows the five month running mean SST time series for the Niño 3 and 3.4 regions relative to a* ***base period climatology of 1950-1979*** *given in Table 1.* ***The base period can make a difference. This standard 30 year base period is chosen as it is representative of the record this century, whereas the period after 1979 has been biased warm and dominated by El Niño events (Trenberth and Hoar 1996a).*** *Mean temperatures are higher in the Niño 3.4 region than in Niño 3 and its proximity to the Pacific warm pool and main centers of convection is the reason for the physical importance of Niño 3.4.*

Thus the use of 1950 to 1979 as the base years for anomalies.

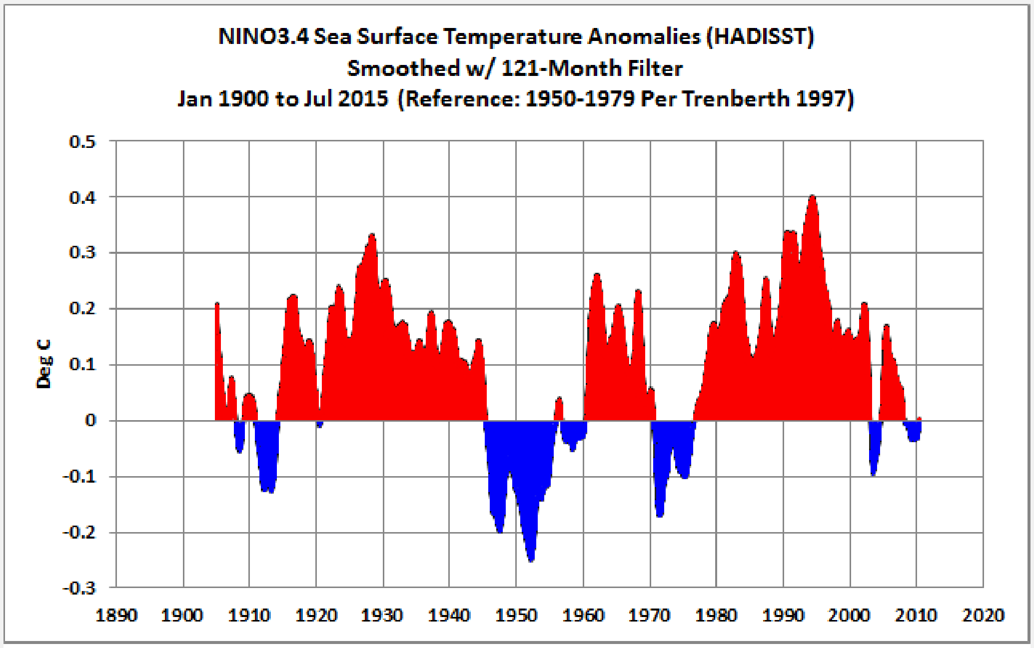


Figure 3.7-35

In Figure 3.7-35 (also updated through July 2015), the NINO3.4 data have been smoothed with a 121-month running-average filter. That's the same filter used by NOAA ESRL for their Atlantic Multidecadal Oscillation Index. I've also colored coded the periods when the 121-month averages are above zero in red, and below zero in blue. It's plainly obvious that El Niño events dominate some decadal and multidecadal periods, and that La Niña events dominate others.

Let's ponder that for a moment. Over decadal and multidecadal periods, the strengths of ENSO phases, along with how often they happen and how long they persist, determine how much heat is released by the tropical Pacific into the atmosphere and how much warm water (at and below the surface) is transported by ocean currents from the tropics toward the poles. Those are the simple realities of ENSO, atmospheric circulation and ocean circulation.

During a multidecadal period when El Niño events dominate (a period when El Niño events are stronger, when they occur more often and when they last longer than La Niña events), more heat than normal is released from the tropical Pacific and more warm water than normal is transported by ocean currents toward the poles—with that warm water releasing heat to the atmosphere along the way.   As a result, global sea surface and land surface temperatures warm during multidecadal periods when El Niño events dominate. They have to warm. There's no way they cannot warm. Conversely, global temperatures cool during multidecadal periods when La Niña events are stronger, last longer and occur more often than El Niño events. That makes sense too because the tropical Pacific is releasing less heat and redistributing less warm water than normal at those times.

HAS ENSO BEEN IMPACTED BY THE HYPOTHETICAL EFFECTS OF MAN-MADE GREENHOUSE GASES?

Global warming activists will often try to claim that the variations in the dominance of ENSO were caused by man-made greenhouse gases and other climate forcings.

First problem: Sea surface temperatures of the NINO3.4 region show little to no warming since 1900. We illustrated and discussed this earlier. (Refer back to the discussions of Figure 3.7-12 and 3.7-13.) Or we can look at the satellite-era sea surface temperature data for the NINO3.4 region. See Figure 3.7-36. The surfaces of the NINO3.4 regions have cooled, not warmed, since November 1981, even with the strong El Niño brewing this year.

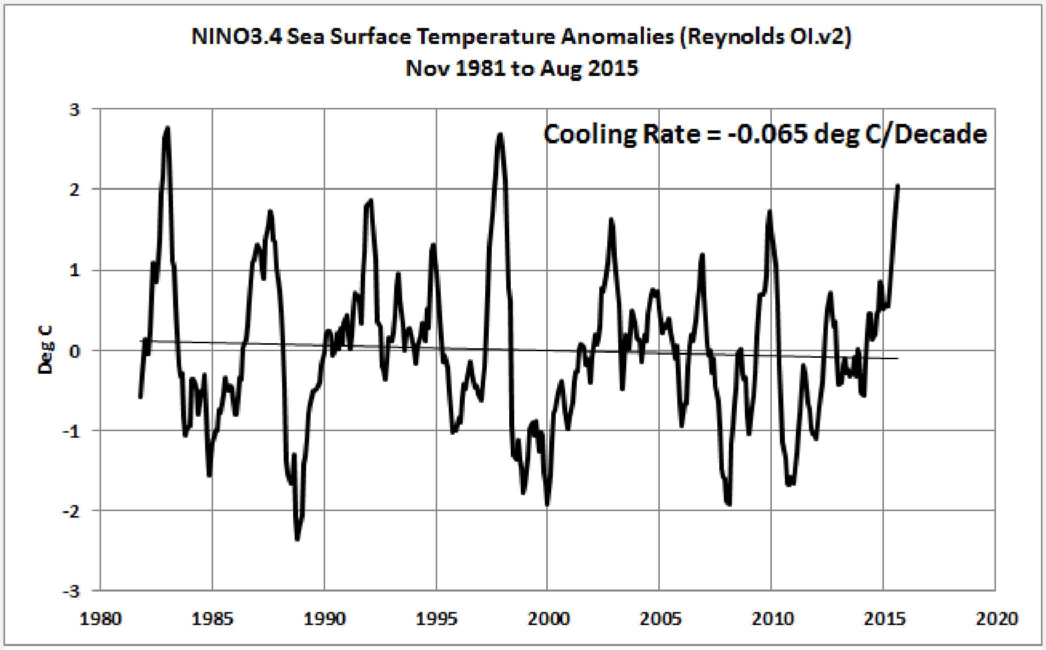


Figure 3.7-36

It's tough to claim global warming is impacting ENSO when the sea surface temperature data for the NINO3.4 region contradict the claims.

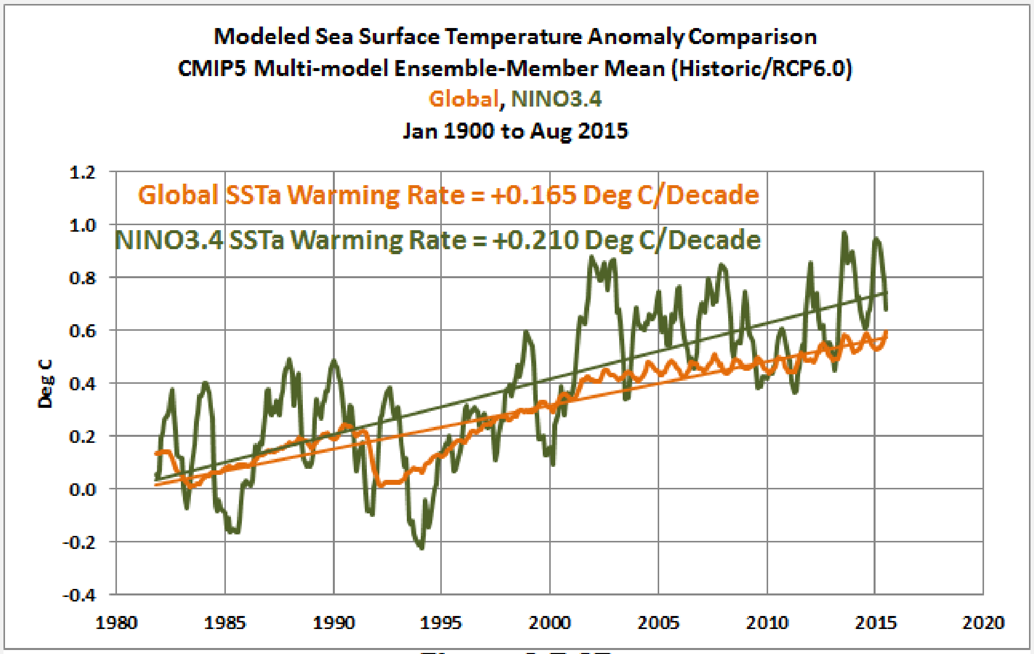


Figure 3.7-37

Second problem: Alarmists have no reference on which to base their claims. Climate models cannot simulate ENSO or the fact that NINO3.4 region sea surfaces show little warming since 1900. And for the period starting in November 1981 (the start of the

Reynolds OI.v2 satellite-enhanced data), climate models show that the surface of the NINO3.4 region of the tropical Pacific should have warmed at a rate of about 0.21 deg C/deg C (about 0.38 deg F/decade), see to Figure 3.7-37, but sea surfaces there have cooled (Figure 3.7-36).

I've included simulated global sea surface temperature anomalies in Figure 3.7-37 as well. The climate models have the relationship backwards. The simulations of sea surface temperature anomalies, shown as the multi-model ensemble-member mean of all of the models in the CMIP5 archive, indicate the surface of the eastern equatorial Pacific should have warmed faster than the global data. In the real world, the surfaces of the eastern equatorial Pacific have cooled since November 1981 (Figure 3.7-36), while the rest of the global oceans have warmed around them…in response to the leftover warm waters from the strong El Niño events (refer back to Figures 3.7-26 and 3.7-27). So any claims about ENSO have no foundations if they're based on climate models.

Third problem: A reanalysis of ENSO since 1871 do not support the claims either. Ray & Giese (2012) **Historical changes in El Niño and La Niña characteristics in an ocean reanalysis** found that El Niño events had not become stronger, or lasted longer, or occurred more often (among other things) since 1871. The Ray & Giese (2012) abstract ends:

> *Overall, there is no evidence that there are changes in the strength, frequency, duration, location or direction of propagation of El Niño and La Niña anomalies caused by global warming during the period from 1871 to 2008.*

Data, climate models and a reanalysis do not support the conjecture that man-made greenhouse gases have had any impact on El Niño and La Niña processes. That really should come as no surprise to anyone who understands ENSO, because ENSO is sunlight fueled.

ON SOME CHAOTIC ASPECTS OF ENSO

In this chapter, we discussed how El Niño and La Niña processes function as a chaotic, naturally occurring, sunlight-fueled, recharge-discharge oscillator. The recharge-discharge oscillator is such that warm water is "stored" between the surface and about 300 meters in depth in the western tropical Pacific.

The discharge occurs as part of the El Niño phase. Vast amounts of warm water are released from the western tropical Pacific. That warm water first travels into the eastern equatorial Pacific, primarily below the surface. There, after rising to the surface, it causes the release of heat to the atmosphere, primarily through evaporation. At the conclusion of the El Niño, the remaining warm waters are redistributed within the oceans.

The recharge occurs during La Niña. Through drastic reductions in cloud cover, a La Niña allows more sunlight than normal to enter the tropical Pacific. This additional downward shortwave radiation entering the tropical Pacific and warming it to depth can replenish part or all of the warm water in the tropical Pacific that was released by the preceding El Niño. And sometimes a La Niña can create more warm water than had been released by the El Niño.

Let's spend a little time on some chaotic portions. As opposed to chaotic, maybe a better choice of words would be non-repeating.

From one point of view, El Niño and La Niña events don't follow a monotonous alternating pattern in time. Every El Niño is not followed by a La Niña and every La Niña isn't followed by an El Niño. That is, El Niños and La Niñas do not cycle back and forth like a sine wave. And the number of years that pass between El Niños varies. Likewise between La Niñas. Further, the strength of an El Niño does not necessarily dictate the strength of a La Niña, and because a La Niña is functionally not the opposite of an El Niño, a La Niña does not counteract an El Nino. (An El Niño is an anomalous state in the tropical Pacific, while a La Niña is simply an exaggerated "normal" state.) There are other ways in which El Niños and La Niñas act in non-repeating fashions.

Every El Niño is different. Atmospheric, ocean surface and ocean subsurface conditions are never quite the same before, during and after an El Niño. An ENSO index, like NINO3.4 sea surface temperature anomalies, cannot tell us how they are different. Example: El Niños come in different "flavors", typically described as Central Pacific and East Pacific El Niños. Because more of the surface of the tropical Pacific is warmed during an East Pacific El Niño, they logically are stronger and have greater impacts on weather throughout the world. An ENSO index like NINO3.4 sea surface temperature anomalies or the Southern Oscillation Index can only tell us the impacts of the El Niños on the metrics being measured for those indices. In other words, NINO3.4 region sea surface temperature anomalies only indicate the impacts of El Niño and La Niña events on the surface temperatures of a specific region of the equatorial Pacific bordered by the coordinates of 5S-5N, 170W-120W, and the Southern Oscillation Index only tells us the impacts of ENSO on the sea level pressure difference between Tahiti and Darwin, Australia. The ENSO indices don't tell us the flavor of the El Niño or the strength of the El Niño as it relates to its flavor. The El Niño Modoki Index was developed to help differentiate between central and eastern Pacific El Niños, but researchers have yet to merge the El Niño Modoki Index with the NINO3.4 or with Southern Oscillation indices to create a better representation of the overall El Niño strength, if such a merged index could be created.

ENSO indices (or a combination of ENSO indices) also do not tell us conditions below the surface of the tropical Pacific. They do not tell us how much warm water was released from the West Pacific warm pool by the Kelvin wave (or waves) during the El Niño evolution. Nor can they tell us how much warm water was distributed eastward at the surface when the equatorial countercurrent (a surface current) strengthens during an El Nino.

Similarly, background conditions (atmosphere and ocean surface and subsurface) are different during La Niña events as well. They too are never quite the same. There are multiyear La Niñas like the 1954-57 La Niña, the 1973-76 La Niña and the 1998-01 La Niña. The 1998-01 La Niña replenished most of the heat lost from the tropical Pacific during the 1997/98 El Nino. But the 1973-76 La Niña not only replenished the heat lost during the 1972/73 El Niño, it also added to the heat content of the tropical Pacific. See Figure 3.7-38. The data have been smoothed with 12-month running-mean filters in it.

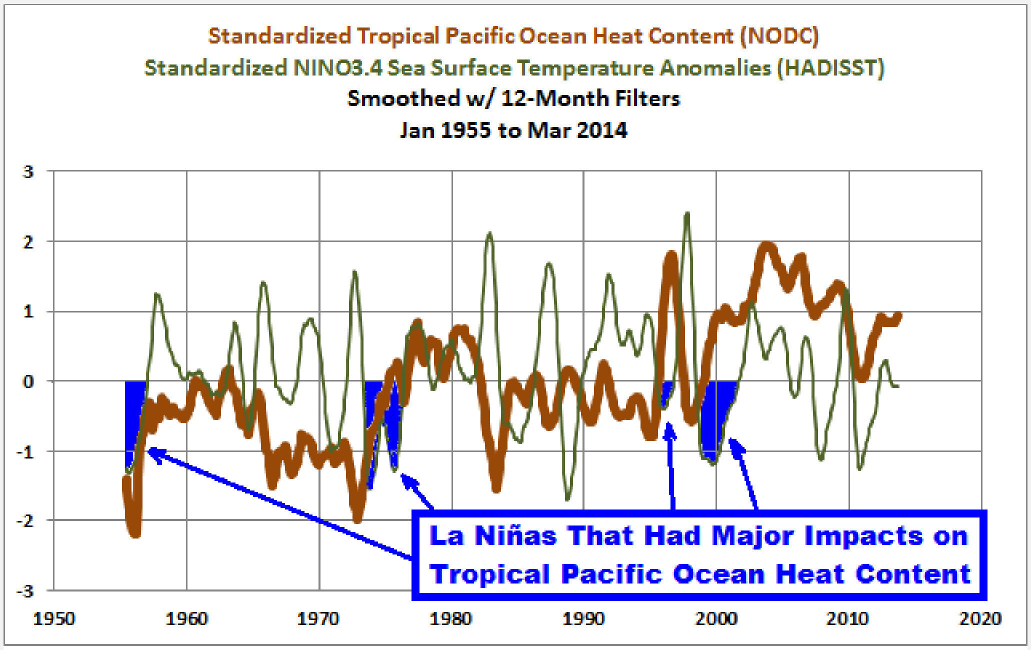


Figure 3.7-38

As noted earlier, there are also La Niñas that do not replenish the warm water released by the El Niño events that came immediately before them. Recent examples: the double-dip La Niñas of 2007/08 and 2008/09 did not replenish the heat lost during the moderate 2006/07 El Niño. Likewise, the heat lost from the 2009/10 El Niño was not replenished by the double dip La Niñas of 2010/11 and 2011/12. The 12-month filters made those double-dip La Niñas appear to be one event in Figure 3.7-38, so I've presented the data with 3-month filters in Figure 3.7-39.

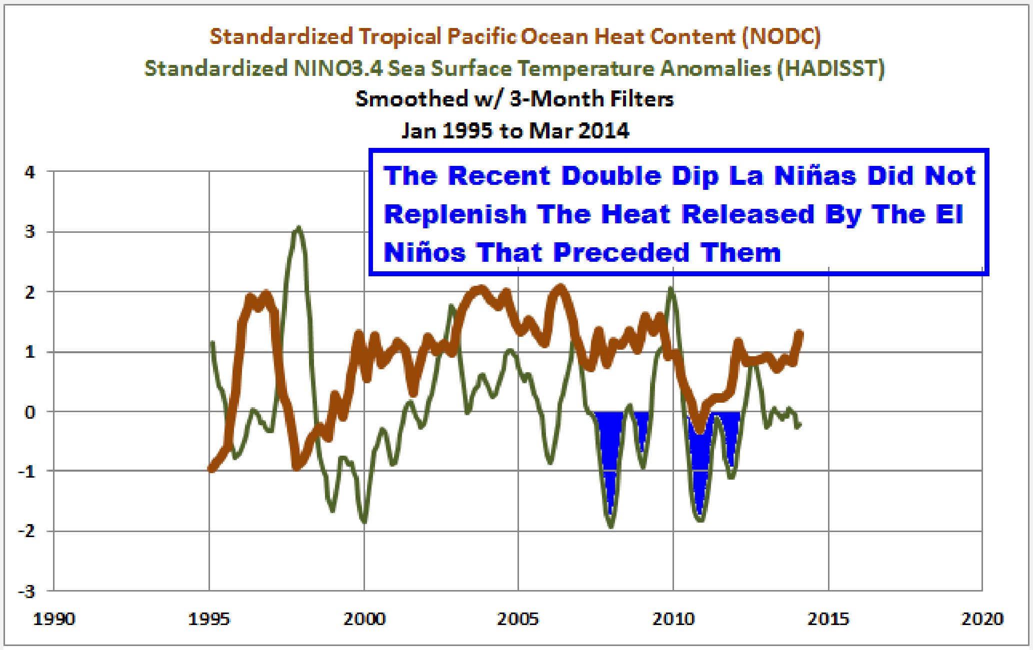


Figure 3.7-39

And then there was the freakish 1995/96 La Niña. It shows up as a relatively weak La Niña in the standard surface-based ENSO indices. See Figure 3.7-40. But all of the warm water for the 1997/98 super El Niño appeared in the tropical Pacific during the 1995/96 La Niña.

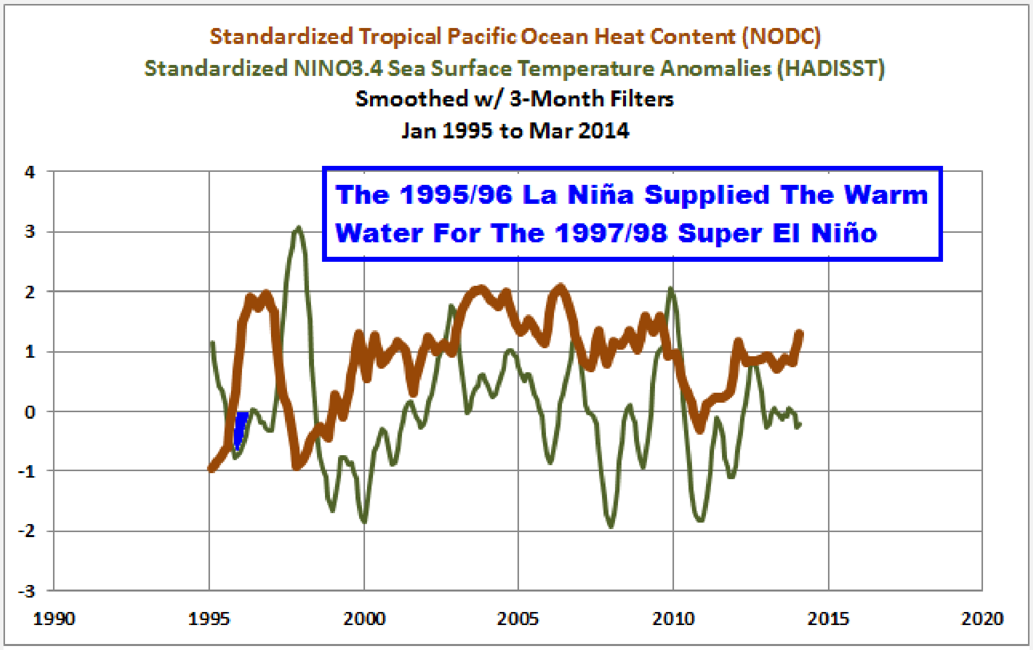


Figure 3.7-40

And aided by the replenishment during the 1998-01 La Niña, the 1995/96 La Niña caused an upward shift in the ocean heat content of the tropical Pacific.

Let me rephrase an earlier discussion. When we look at our standard ENSO indices, we see quasi-cyclical behavior. But that quasi-cyclical behavior does not appear, for example, in the ocean heat content data for the tropical Pacific. The ocean heat content there helps to highlight another aspect of the non-repeating nature of ENSO. We've seen that in the responses to La Niña events of the ocean heat content data for the tropical Pacific. Refer again to Figures 3.7-38 through 3.7-40.

On the other hand, the ocean heat content of the tropical Pacific does not always respond the same to El Niño events. Referring to Figure 3.7-41 below, the 2002/03 and 2009/10 El Niños were close to being comparable in strength based on the NINO3.4 data. The 2009/10 El Niño was stronger than the 2002/03 El Niño, but the difference in strength cannot explain the dissimilarity in how the ocean heat content for the tropical Pacific responded to those El Niños. The ocean heat content of the tropical Pacific dropped in response to the 2009/10 El Niño, but it <u>increased</u> during the 2002/03 El Niño.

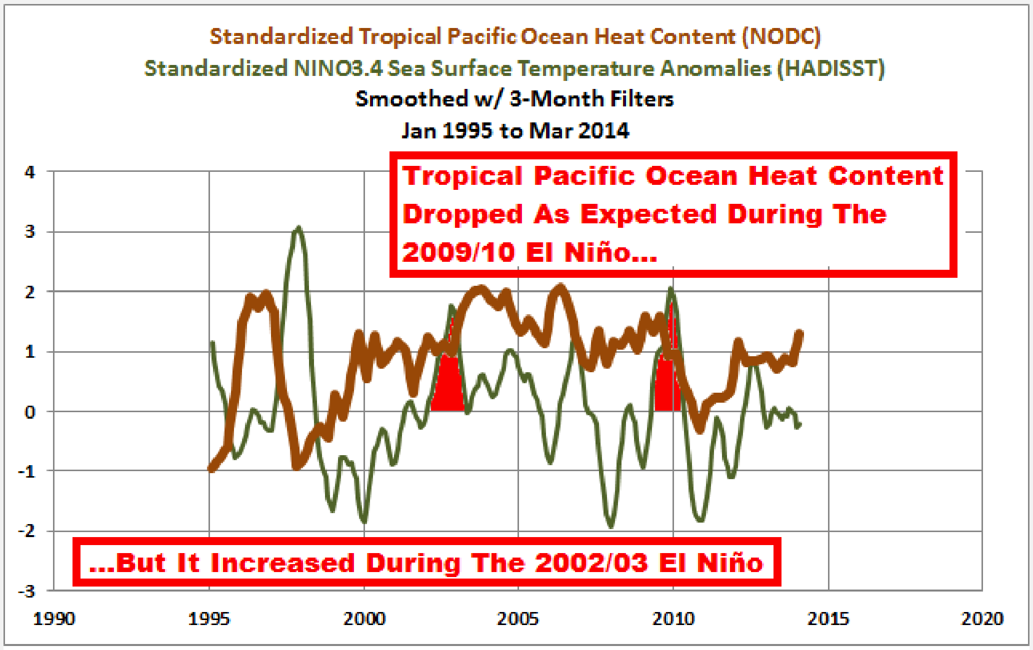


Figure 3.7-41

The 2002/03 La Niña should have released heat from the tropical Pacific. More of the surface of the tropical Pacific was covered with warm water than normal. This should have led to more heat loss than normal due to evaporation. Why then did the ocean heat content of the tropical Pacific increase during the 2002/03 El Niño? Keep in mind that, by selecting data based on coordinates, we're placing imaginary borders around the tropical Pacific, where no borders exist. Surface and subsurface ocean currents are constantly carrying waters of varying temperature and salinity into and out of the tropical Pacific, impacting its ocean heat content. Consider that the 1997/98 El Niño was a monstrous event. It released a tremendous amount of warm water from below the surface of the western tropical Pacific. Much of the left over warm water was circulated out of the tropical Pacific in its aftermath. It's likely the increase in ocean heat content during the 2002/03 El Niño was simply some of that warm water returning to the tropical Pacific.

A RETURN TO THE SUNLIGHT-FUELED ASPECT OF ENSO

Let's move onto the sunlight-fueled portion of our description how El Niño and La Niña processes function.

Earlier in the chapter we presented quotes from two papers by Dr. Kevin Trenberth of NCAR:

- Trenberth et al. (2002) Evolution of El Niño-Southern Oscillation and global atmospheric surface temperatures
- Trenberth and Fasullo (2011) Tracking Earth's Energy: From El Niño to Global Warming

In those papers, Trenberth basically stated that cloud cover decreases over the tropical Pacific during La Niñas and the lower-than-normal cloud cover allows sunlight to penetrate the tropical Pacific and replenish the warm water that had been released and redistributed by the preceding El Niños. And we also presented a couple of graphs from Pavlakis et al (2008) ENSO surface shortwave radiation forcing over the tropical Pacific. Those graphs confirmed that there are drastic increases in sunlight reaching the surface of portions of the tropical Pacific during La Niñas.

In failed attempts to counter those discussions, proponents of the hypothesis of human-induced global warming will refer to the recent decrease in the output of the sun, and sometimes they'll present Total Solar Irradiance data, Figure 3.7-42, to support their statements. The total solar irradiance data show the variations in the output of the sun as measured at the top of the atmosphere. And total solar irradiance has decreased since the late 1970s. How then, they argue, could sunlight be responsible for increases in temperature and ocean heat?

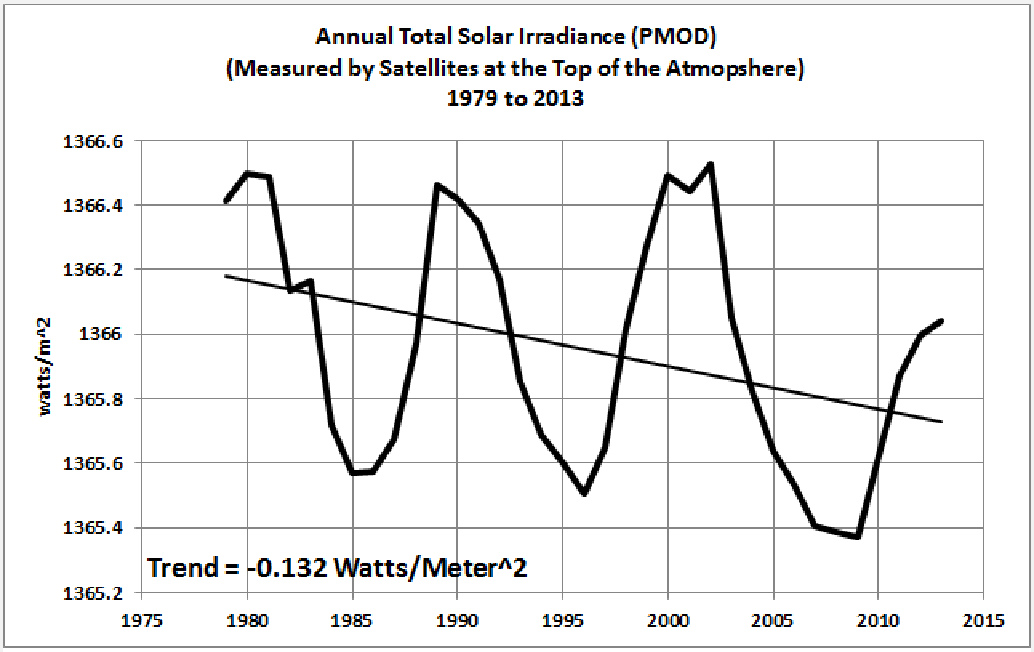


Figure 3.7-42

What they fail to consider, intentionally (misdirection) or unintentionally (unfamiliarity), is that sunlight at the top of the atmosphere does not necessarily equal the amount of sunlight reaching the surface of the tropical Pacific…or the surface of the globe for that matter. Between the top of the atmosphere and the surface, there are clouds and both natural and man-made aerosols. Those clouds and aerosols cause the amount of sunlight reaching the surface to rise and fall. As a result, our interest should be how much sunlight reaches the surface, not the top of the atmosphere.

Unfortunately, there are very few instrument-based measurements of sunlight (downward shortwave radiation) at the surface. We must, therefore, rely on outputs of specialized climate models that use data as inputs: sea surface temperature data, cloud cover data at different heights, aerosol data, etc. As discussed in Chapter 2.2 – Different Types of Climate Models, that type of computer model is known as a reanalysis. Satellite-based data generally starts in 1979, as do the reanalyses that use them. That period covers most of the recent warming period, which began in the mid-1970s.

There are a number of reanalyses available through the KNMI Climate Explorer. See their webpage here. Some, but not all, present downward shortwave radiation at the surface, but only two of them start in 1979 and have been updated into 2014. One is the ERA-Interim reanalysis from the European Centre for Medium-Range Weather Forecasts (ECMWF). The other is the NCEP-DOE Reanalysis-2, which is the product of a joint effort between the NOAA National Centers for Environmental Prediction

(NCEP) and the Department of Energy (DOE). So we'll present and discuss the downward shortwave radiation (sunlight) outputs of those two reanalyses.

NOTES:

1. Unfortunately, KNMI removed the NCEP-DOE Renalysis-2 outputs from their Climate Explorer between the time this was written and now. So you cannot easily verify what's being presented in the following.

2. The outputs of reanalyses are often referred to as data. But they are not observations-based data for many metrics, like downward shortwave radiation at the surface. Those are calculated values, and they rely on the assumptions the modelers made when writing the software. So we have to take the reanalyses with a pinch of salt. One thing is certain, they do not support the conclusion that only man-made greenhouse gases were responsible for the warming, which is based on fatally flawed climate models…which have to be taken with a truck-load of salt.

[End notes.]

All we need to do is examine the reanalysis outputs of global downward shortwave radiation at the surface to counter those failed "the sun could not have done it" arguments. But we'll also take a look at the amount of sunlight reaching the equatorial Pacific.

Figure 3.7-43 shows the global downward shortwave radiation (sunlight) reaching all of Earth's surfaces, according to average of those two reanalyses: the ECMWF ERA-Interim reanalysis and the NCEP-DOE Reanalysis-2. I'll provide full-sized illustrations in the upcoming chapter about solar variability (Chapter 3.19 – Natural Forcing: Solar Radiation), and also show the outputs of the individual reanalyses. The right-hand graph shows the raw average of the two reanalyses, while on the left, the outputs have been smoothed with 61-month filters, basically 5-year filters.

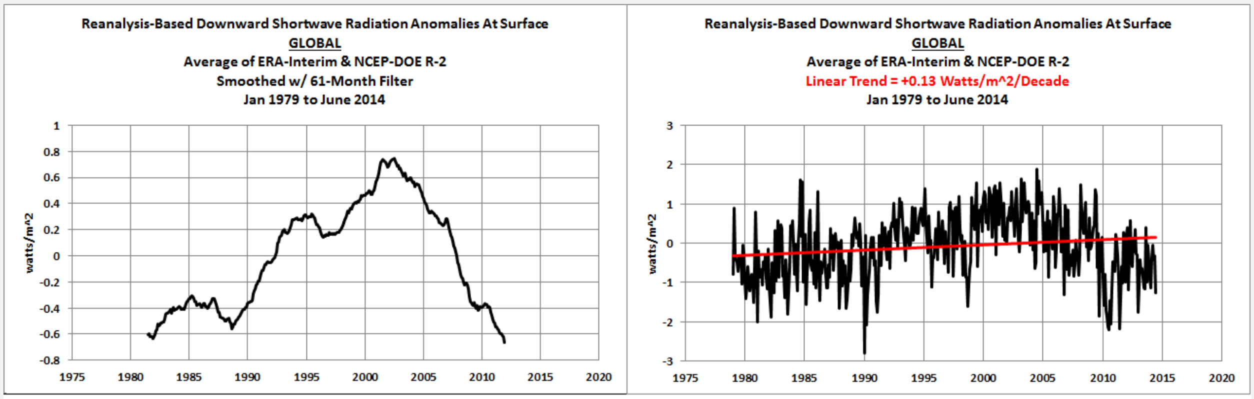


Figure 3.7-43

As shown, based on the outputs of those two reanalyses, the amount of sunlight reaching the surface of our planet increased drastically from the late-1970s until early-2000s, almost 1.4 watts/m^2 based on the smoothed data, and has decreased since then, returning to the levels they were at near the beginning of this time period. Because the rise was more than a decade longer than the decline, the long-term trend is a positive 0.13 watts/m^2/decade since 1979, as illustrated in the right-hand graph. The outputs of those two reanalyses contradict the argument that the decreasing output of the sun would have slowed global warming.

Back to our discussion of ENSO.

Figure 3.7-44 presents the downward shortwave radiation outputs of the ERA-Interim and NCEP-DOE R-2 reanalyses for the eastern equatorial Pacific (6S-6N, 180-90W), the region used for the Cold Tongue Index. They are being presented in anomaly form. The time period is January 1979 to June 2014. Both outputs have been smoothed with 12-month filters to reduce the volatility present in the monthly outputs. As shown, there are large short-term decreases and rebounds in the sunlight reaching the eastern equatorial Pacific. The most noticeable are in response to the 1982/83 El Niño and the 1997/98 El Niño. Dips and rebounds from lesser El Niños are also visible, as are the temporary increases in downward shortwave radiation during La Niñas.

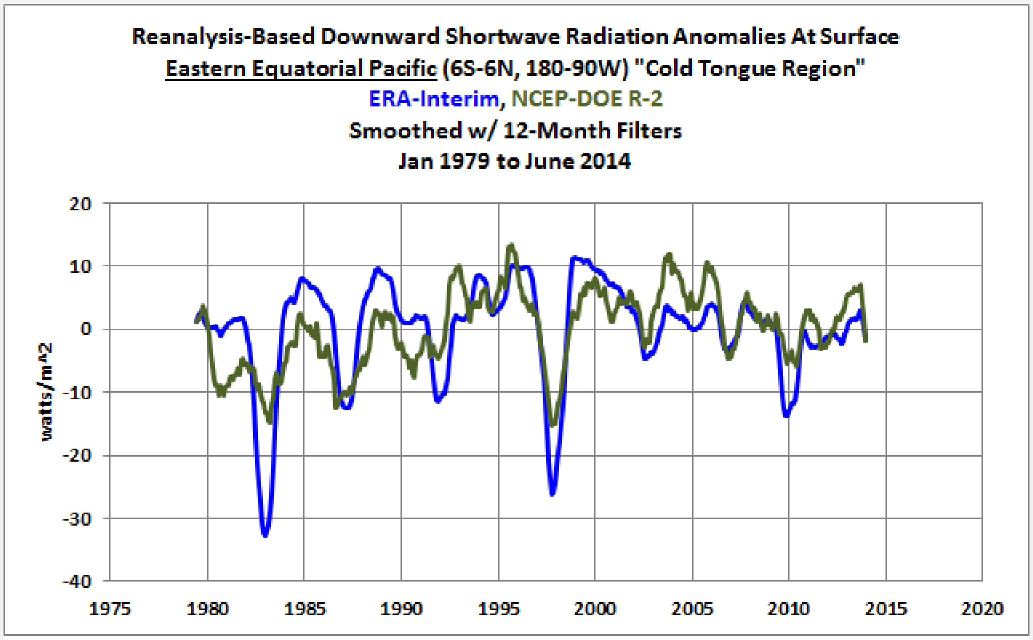


Figure 3.7-44

Something else also stands out in the graph. There was a steady increase in sunlight reaching the eastern equatorial Pacific from the late 1970s until the turn of the century, with a minor decline afterwards.

This long-term rise and fall in sunlight reaching the surface is also noticeable if we compare the average of the outputs of those reanalyses to the inverted sea surface temperature anomalies of the Cold Tongue Region. See Figure 3.7-45. The data and the average of the reanalyses outputs have been standardized and then smoothed with 12-month running-mean filters. With the Cold Tongue Index data inverted, El Niños are downward spikes and La Niñas are upwards. As shown, the sunlight reaching the surface of the eastern equatorial Pacific was lower than expected before 1990 and after about 2006, but it was greater than expected in the mid-1990s and early-2000s. So something other than what we might expect from ENSO was impacting how much sunlight reached the surface of the eastern equatorial Pacific.

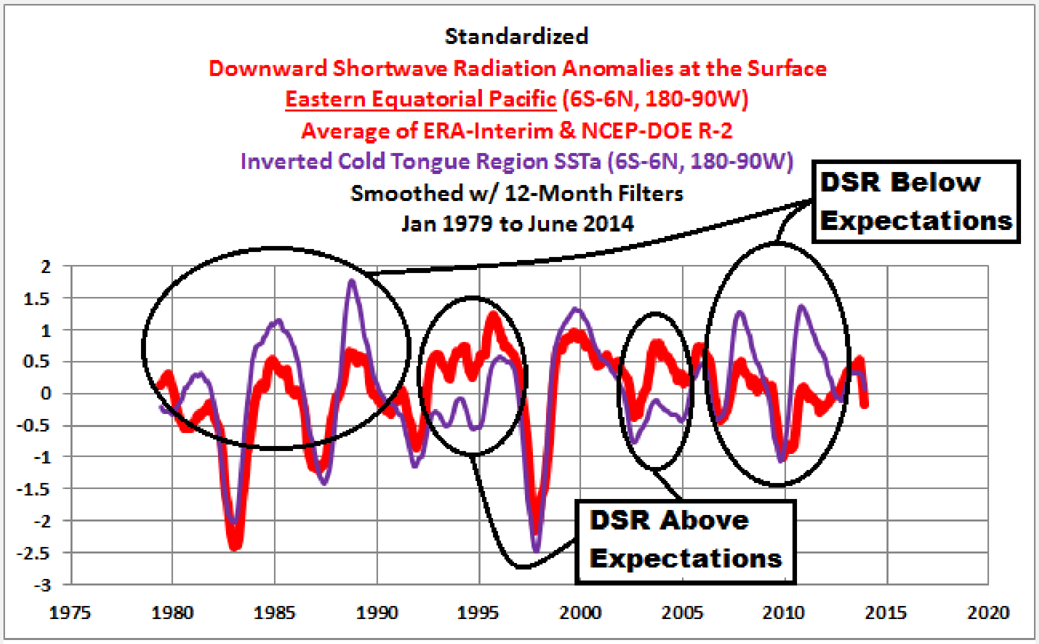


Figure 3.7-45

Note: The Cold Tongue Index is an ENSO index similar to the sea surface temperature anomalies of the NINO3.4 region. Where the NINO3.4 region is bordered by the coordinates of 5S-5N, 170W-120W, the Cold Tongue region is slightly broader and extends farther east, encompassing the coordinates of 6S-6N, 180-90W. [End note.]

Let's expand our view to the entire equatorial Pacific, using the coordinates of 6S-6N, 120E-80W. See Figure 3.7-46, which shows both reanalyses separately. The reanalyses outputs of downward shortwave radiation reaching the surface of the equatorial Pacific show a more distinct long-term variation.

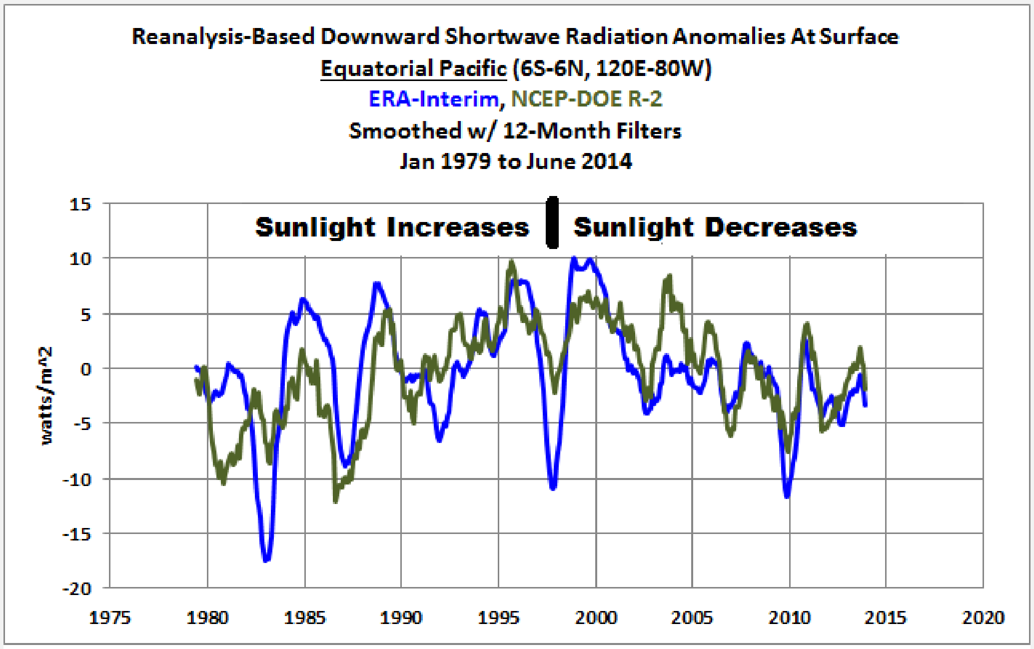


Figure 3.7-46

Keeping in mind that the equatorial Pacific stretches almost halfway around the globe, we can see in Figure 3.7-46 that the sunlight reaching the surface of the equatorial Pacific rose until around the late 1990s and then decreased afterwards. If we look at the average of the outputs of those reanalyses and smooth the average with a 61-month filter to reduce the variations resulting from ENSO, Figure 3.7-47, the rise and fall and the peak in the late 1990s are blatantly obvious.

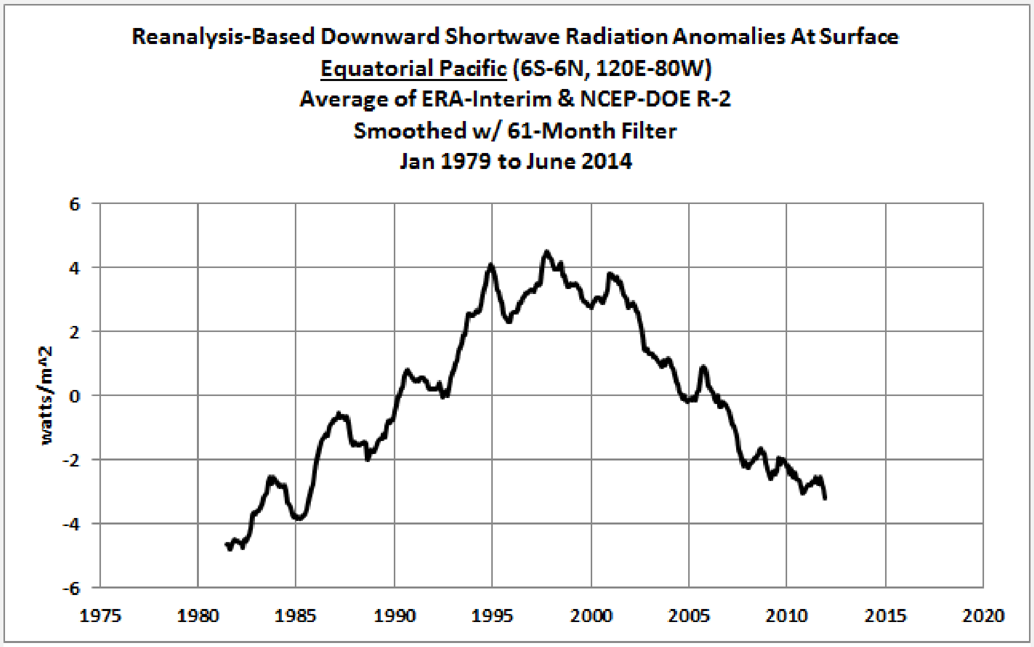


Figure 3.7-47

Based on the smoothed reanalysis outputs, the sunlight reaching the surface of the equatorial Pacific increased more than 8 watts/m^2 from the late 1970s until the late 1990s. That appears to be a reasonable explanation for why the ocean heat content of the tropical Pacific jumped upwards in response to the 1995/96 La Niña.

CLIMATE MODELS DO NOT PROPERLY SIMULATE EL NIÑO AND LA NIÑA PROCESSES

Bellenger, et al. (2013): ENSO Representation in Climate Models: From CMIP3 to CMIP5 is a recent confirmation of how poorly climate models simulate El Niños and La Niñas and their fundamental processes. Preprint copy is here. The section titled "Discussion and Perspectives" begins:

> *Much development work for modeling group is still needed in order to correctly represent ENSO, its basic characteristics (amplitude, evolution, timescale, seasonal phaselock…) and fundamental processes such as the Bjerknes and surface fluxes feedbacks.*

Notes: 1) "Phaselock" refers to the fact that El Niño and La Niña events are tied to the seasonal cycle. 2) "Bjerknes feedback", very basically, relates to how the tropical Pacific and the atmosphere above it are coupled; i.e., they are interdependent, a change in one causes a change in the other and they provide positive feedback to one another. The existence of this positive "Bjerknes feedback" suggests that El Niño and La Niña events will remain in one mode until something interrupts the positive feedback.

Let me rephrase that quote from Bellenger, et al. (2013): Climate models do not properly simulate how El Niño and La Niña events evolve, their strengths, their timing and how they are tied to the seasonal cycle. Even more telling, according to Bellenger, et al. (2013), "much development work…is still needed" for the basic "fundamental processes" of El Niño and La Niña.

A predecessor to Bellenger, et al. (2013) was Guilyardi, et al. (2009) Understanding El Niño in Ocean-Atmosphere General Circulation Models: Progress and Challenges. It too is a detailed overview of the many problems climate models have in their attempts to simulate El Niños and La Niñas. The authors of that study cite more than 100 other papers. The following is one of the revealing statements in Guilyardi, et al. (2009):

> *Because ENSO is the dominant mode of climate variability at interannual time scales, the lack of consistency in the model predictions of the response of ENSO to global warming currently limits our confidence in using these predictions to address adaptive societal concerns, such as regional impacts or extremes (Joseph and Nigam 2006; Power, et al. 2006).*

In other words, because climate models cannot accurately simulate El Niño and La Niña processes, the authors of that paper have little confidence in climate model projections of regional climate or of extreme events.

Guilyardi et al. also mention a critical shortcoming of climate model simulations of ENSO. They write (my boldface):

> *…These recurrent biases,already present in CMIP1 15 yr ago, arise from numerous factors including overly strong trade winds, leading to increased cooling via oceanic upwelling, mixing, and latent heat flux to the atmosphere; a diffuse thermocline structure, leading to improper sensitivity of SST to anomalous upwelling and vertical mixing;* ***insufficient surface and penetrating solar radiation****, and weak ocean vertical mixing in the subtropics, leading to subsurface temperature errors along the equator; and weak tropical instability waves, resulting in too little meridional spreading of SST anomalies during cold events (Meehl et al. 2001; Luo et al. 2005; Wittenberg et al. 2006; Lin 2007a)…*

That is, climate models use too little sunlight in their efforts to simulate El Niño and La Niña processes. El Niños are sunlight-fueled events, with the warm water created during La Niñas. Climate modelers continue their efforts to force global warming with downward longwave (infrared) radiation, when in the real world much of that warming can be attributed to Mother Nature through the chaotic, sunlight-fueled, recharge-discharge aspects of ENSO.

OOPS, ALMOST FORGOT

The upward steps are also plainly visible in lower troposphere temperature data for the mid-latitudes of the Northern Hemisphere (20N-65N) after the 1997/98 El Niño…better in the RSS data than the UAH data. See Figure 3.7-48. Unfortunately, the upward shift after the 1986/87/88 El Niño is hidden by the impacts (dip and rebound) of the eruption of Mount Pinatubo in 1991.

Note: The Trenberth Jumps also used to be visible (past tense) in the GISS LOTI data for those latitudes before GISS adopted the pause-buster sea surface temperature data from NOAA. [End note.]

I first noticed the upward shift at those latitudes in the Hovmoller diagram provided by RSS at their website. Figure 3.7-49 is an annotated version of that RSS Hovmoller diagram that I included as Figure 5-64 in my book *Who Turned on the Heat? – The Unsuspected Global Warming Culprit: El Niño-Southern Oscillation*.

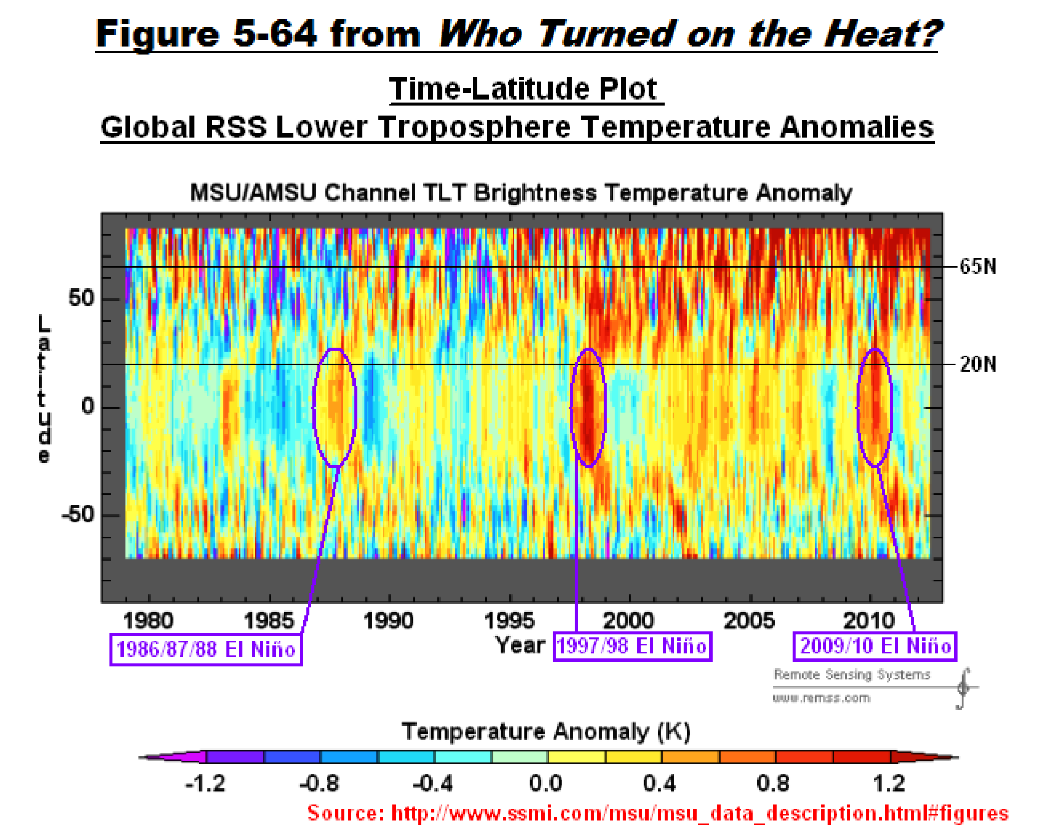


Figure 3.7-49

There I wrote:

> Figure 5-64 is a time-latitude plot (Hovmöller) of Global Lower Troposphere Temperature anomalies prepared by **Remote Sensing Systems**. It is available at their website toward the bottom of their **Description of MSU and AMSU Data Products** webpage. The temperature anomalies are color-coded. See the scale below the Hovmöller. The horizontal axis (x-axis) is time, running from the start of the dataset in January 1979 and ending in June 2012. The vertical axis (y-axis) is latitude, with the North Pole at the top and the South Pole at the bottom. I've also highlighted the latitudes of 20N-65N with thin black lines.
>
> Also, I've highlighted in purple the 1986/87/88, 1997/98, and 2009/10 El Niño events. As you'll recall, the tropical Pacific releases more heat than normal during an El Niño, primarily through evaporation. The warm, moist air rises, cooling as it rises. When it condenses, it releases heat. That's the reason for the warm temperature anomalies in the tropics at 3000 feet during the El Niño events. The La Niña events following them can be seen to the right of the highlighted El Niño, as can the lesser (secondary) El Niño events between them the major events. The 1982/83 El Niño should have shown warming comparable to the 1997/98 El Niño, but it was counteracted by the eruption of El Chichon.

> Let's focus on the 1997/98 El Niño, the strongest of the strong events. Right after the peak warming of the tropics in early 1998 the mid-to-high latitudes warm (20N-65N, between the two thin black lines). They stay warm during the La Niña. Again, this contradicts the assumption that the globe cools proportionately during La Niña events. The lesser El Niño events in 2002/03, 2004/05 and 2006/07 then maintain the elevated temperatures. The same thing happens again with the 2009/10 El Niño. It helps to maintain the Lower Troposphere Temperature anomalies at their elevated levels. Moving back in time to the 1986/87/88 El Niño, the same thing may have happened, but it's difficult to tell with the color coding and the amount of warming.

The climate science community treats the responses to ENSO seen in the instrument temperature record as noise on a global warming trend, where the warming was created by the emissions of greenhouse gases, but data contradict their incorrect assumptions.

WHAT ARE EL NIÑO AND LA NIÑA YEARS?

You might see a specific year referred to as an "El Niño year" or a "La Niña year" during a discussion of global surface temperatures. Typically, they are referring to the decay year of the El Niño or La Niña due to the time lag for global surface temperatures to respond to the ENSO event. So they might say 1998 and 2010 were El Niño years, because surface temperatures peaked in those years to the 1997/98 and 2009/10 El Niños.

A FINAL NOTE ABOUT ENSO

Bottom line: Because ENSO processes act as a chaotic, naturally occurring, sunlight-fueled, recharge-discharge oscillator, statistical methods, simple or complex, cannot be used to account for its long-term impacts on global surface temperatures and on the ocean heat content of the global oceans. Energy fluxes local to the tropical Pacific and globally for each ENSO event, both El Niños and La Niñas, must be examined separately. With climate science still focused on (politically motivated) hypothetical impacts of greenhouse gases, I do not expect to see that type of analysis in my lifetime.

FURTHER READING

A good portion of my articles at my blog Climate Observations and at WattsUpWithThat are about the processes that make up the phenomena called El Niño and La Niña, so you might say I'm well-written on the subject. Those posts can be found at my blog under the heading of El Nino-La Nina Processes.

My book about ENSO is titled Who Turned on the Heat? – The Unsuspected Global Warming Culprit, El Niño Southern Oscillation. The first section of that book includes a series of 30+ cartoon-like illustrations that walk the readers through the processes of ENSO. I also published that section of the book at my blog and at WattsUpWithThat under the title of An Illustrated Introduction to the Basic Processes that Drive El Niño and La Niña Events.

Other blog posts that hold keys to understanding ENSO processes include:

- El Niño and La Niña Basics: Introduction to the Pacific Trade Winds
- La Niñas Do NOT Suck Heat from the Atmosphere
- ENSO Basics: Westerly Wind Bursts Initiate an El Niño

And there are always the posts that respond to lies told about my efforts to educate readers about ENSO. They include:

- Untruths, Falsehoods, Fabrications, Misrepresentations
- Untruths, Falsehoods, Fabrications, Misrepresentations — Part 2

And there are general discussions in my series of posts about the on-again, off-again El Niño in 2014. See the 2014-15 El Nino Series.

One of my favorite NOAA references is the Frequently-(well, at least once)-asked-questions about El Niño, by Dr. William Kessler of the NOAA Pacific Marine Environmental Laboratory (PMEL). That was one of the webpages that found very helpful when I first began to study ENSO.

NOAA also started their ENSO blog in 2014. Their articles would be helpful to someone new to the topic of El Niño and La Niña.

There are a multitude of other webpages by NOAA, Australia's BOM and the like about El Niño and La Niña. Unfortunately, there are too many to list.

3.8 – Atmospheric Modes - General

In this chapter, we'll provide a brief overview of atmospheric index data that are commonly referenced in discussions of weather and climate change. Often times these atmospheric indices are referred to as "teleconnection patterns". We'll examine many of these indices individually in upcoming chapters.

The NOAA Climate Prediction Center (CPC) provides a relatively easy-to-understand introduction to teleconnection patterns. The following are the first few paragraphs:

> *The atmospheric circulation is well-known to exhibit substantial variability. This variability reflects weather patterns and circulation systems that occur on many time scales, lasting from a few days (characteristic of a normal storm system and frontal passage), to a few weeks (characteristic of a mid-winter warm-up or a mid-summer wet period) to a few months (characteristic of particularly cold winters or hot summers), to several years (characteristic of abnormal winters for several years in a row), to several centuries (characteristic of long-term climate change).*
>
> *The term "teleconnection pattern" refers to a recurring and persistent, large-scale pattern of pressure and circulation anomalies that spans vast geographical areas. Teleconnection patterns are also referred to as preferred modes of low-frequency (or long time scale) variability. Although these patterns typically last for several weeks to several months, they can sometimes be prominent for several consecutive years, thus reflecting an important part of both the interannual and interdecadal variability of the atmospheric circulation. Many of the teleconnection patterns are also planetary-scale in nature, and span entire ocean basins and continents. For example, some patterns span the entire North Pacific basin, while others extend from eastern North America to central Europe. Still others cover nearly all of Eurasia.*
>
> *All teleconnection patterns are a naturally occurring aspect of our chaotic atmospheric system, and can arise primarily a reflection of internal atmospheric dynamics. Additionally, some of these patterns, particularly those over the North Pacific, are also sometimes forced by changes in tropical sea-surface temperatures and tropical convection associated with both the ENSO cycle* ***(Mo and Livezey 1986, Barnston and Livezey 1991)*** *and the Madden-Julian Oscillation (MJO).*

> *Teleconnection patterns reflect large-scale changes in the atmospheric wave and jet stream patterns, and influence temperature, rainfall, storm tracks, and jet stream location/ intensity over vast areas. Thus, they are often the culprit responsible for abnormal weather patterns occurring simultaneously over seemingly vast distances.*

Note: I can't find a link to Mo and Livezey (1986) "Tropical-extratropical geopotential height teleconnections during northern hemisphere winter". "Barnston and Livezey 1991" appears to be Barnston, Livezey and Halpert (1991) Modulation of Southern Oscillation-Northern Hemisphere Mid-Winter Climate Relationships by the QBO. [End note.]

Atmospheric circulation indices are generally based on sea level (barometric) pressure measurements, which determine the weight of the column of air above the measuring location.

Atmospheric circulation indices are important in discussions of global warming and climate change, because the circulation patterns to which they're related can and do influence when and where rainfall occurs and when and where temperatures are warmer or cooler than normal. Just like the ocean circulation processes of ENSO and the Atlantic Multidecadal Oscillation, the atmospheric circulation patterns can also vary for a decade or more; that is, the positive or negative phase of a pattern can dominate over decadal and multidecadal timescales. During these extended time periods where atmospheric circulation persists in a specific phase, some regions would tend to be warmer (or cooler) and would tend to have more (or less) precipitation. For example, you may find studies where the authors conclude that a long-term shift in atmospheric circulation is responsible for an extended drought.

Because atmospheric circulation patterns relate to wind patterns, they can also impact sea surface temperatures and ocean heat uptake.

Let's start our discussions with the Southern Oscillation.

3.9 – Atmospheric Mode – Southern Oscillation (The SO of ENSO)

We discussed the Southern Oscillation in 3.7 – Ocean Mode: El Niño and La Niña. Refer to the discussion and to Figures 3.7-14 and 3.7-15 under the heading of THE SOUTHERN OSCILLATION INDEX.

In short, the Southern Oscillation Index is a sea level pressure-based index. It represents the difference in the observed sea level pressure anomalies measured in Tahiti and in Darwin, Australia. It tends to capture the impacts of El Niño and La Niña events on the atmospheric circulation of the tropical South Pacific (off the equator). Because El Niño and La Niña events take place along the equator in the Pacific, and because those two measuring locations are not on the equator, the Southern Oscillation Index data are also, unfortunately, impacted by weather that does not relate to El Niños and La Niñas.

Long-term Southern Oscillation Index data (since 1876) are available from Australia's Bureau of Meteorology (BOM). See Figure 3.9-1. The BOM considers El Niño conditions to exist when the Southern Oscillation Index values are below or equal to -8.0, and La Niña conditions exist when values are greater than or equal to +8.0.

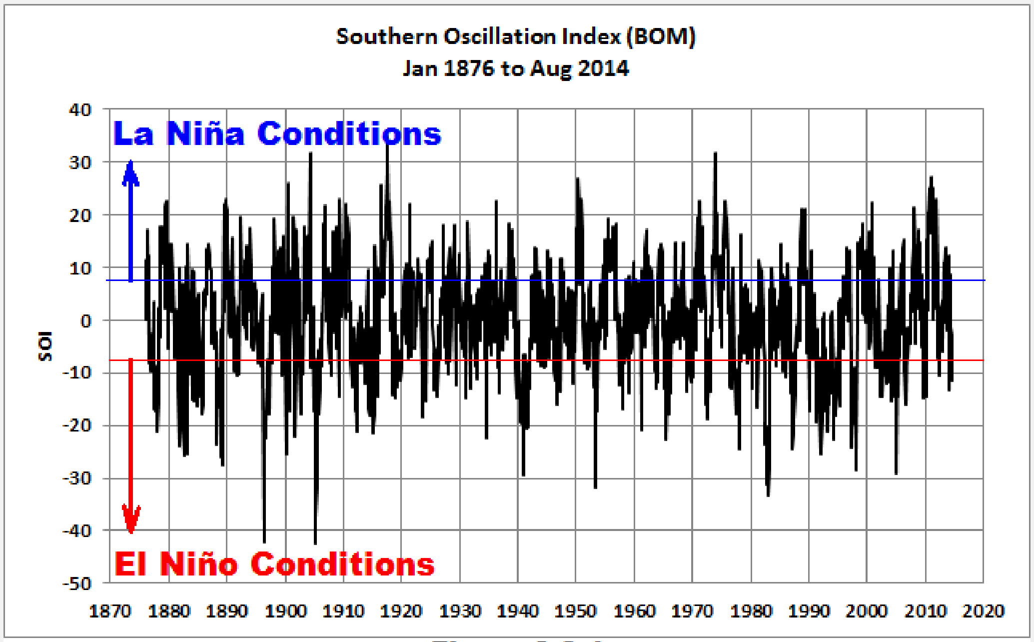


Figure 3.9-1

Keep in mind, the Southern Oscillation Index values before the 1930s are questionable. We'll refer again to Trenberth (1997) The Definition of El Niño. There he writes (my boldface):

> *Various versions of the SOI exist although, in recent years, most deal only with atmospheric pressures and usually only those at Darwin and Tahiti. In using the SOI based on just two stations, it must be recognized that there are many small-scale and high frequency phenomena in the atmosphere, such as the Madden–Julian Oscillation, that can influence the pressures at stations involved in forming the SOI but that do not reflect the Southern Oscillation itself. Accordingly, the SOI should only be used when monthly means are appropriately smoothed (Trenberth 1984; Trenberth and Hoar 1996a).* ***For many years, Tahiti data were available only after 1935. Ropelewski and Jones (1987) outline an extension of the SOI prior to then using newly discovered Tahiti data, and they also discuss different ways of standardizing the data for use in the SOI. However, there are questions about the integrity of the Tahiti data prior to 1935 (Trenberth and Hoar 1996a) as the Tahiti–Darwin correlation is much lower in spite of strong evidence that the SO was present from other stations and the noise level and variance in the early Tahiti data are higher than in the more recent period****.*

As shown above in Figure 3.9-1, the monthly Southern Oscillation Index data are very volatile. So let's do what Trenberth recommends and smooth the data. We'll use a 12-month running-average filter. The results are shown in Figure 3.9-2.

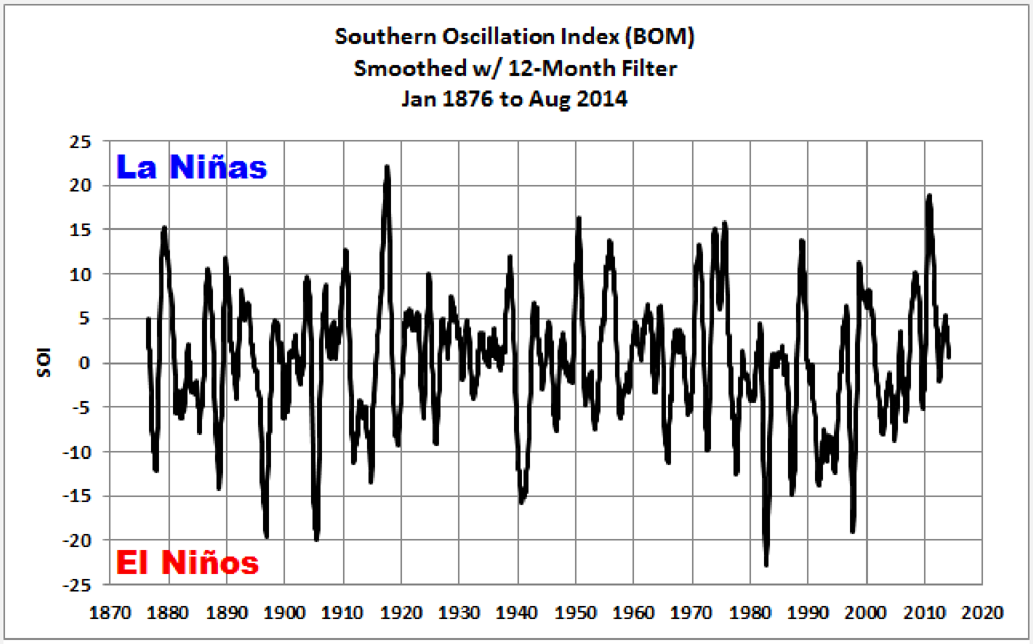


Figure 3.9-2

It's unfortunate that the data before the 1930s are questionable. According to the BOM Southern Oscillation Index, there were El Niño events in the 1896/97 and one around 1905 that were comparable to the "super" El Niños of 1982/83 and 1997/98.

The Southern Oscillation Index also appears to have decadal and multidecadal variations in the dominance of El Niño and La Niñas. Let's confirm that by smoothing the data with a 121-month running-average filter. See Figure 3.9-3. You'll note I've also color-coded the graph to indicate periods when El Niño or La Niña events dominated.

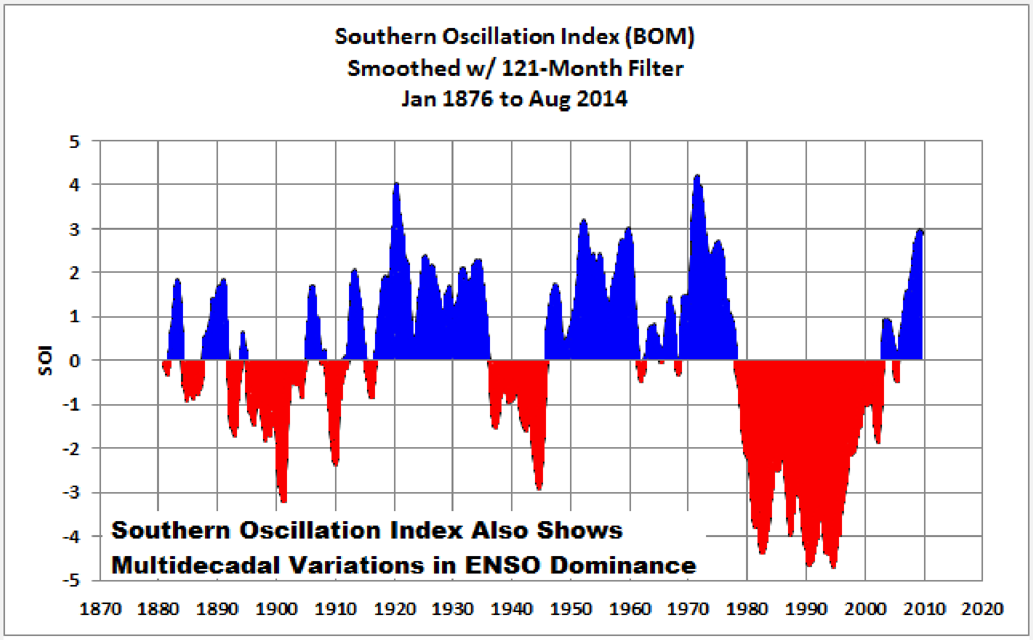


Figure 3.9-3

According to the Southern Oscillation Index, El Niño events dominated from the late-1970s to the early-2000s. That agrees with the sea surface temperature-based indices. La Niña events were dominant from the early-1940s to the late-1970s, but there appears there could be some disagreement with the sea surface temperature indices during that time. Before the mid-1930s, the Southern Oscillation Index data are questionable.

I've compared the Southern Oscillation Index data from BOM (which I've inverted so that El Niños are upward) with the HADISST-based NINO3.4 sea surface temperature anomalies in Figure 3.9-4. For the comparison in Figure 3.9-4, the NINO3.4 data were standardized (divided by their standard deviation). The Southern Oscillation Index from BOM is also standardized, but they also multiply it by 10, so I divided the SOI data by 10 in Figure 3.9-4.

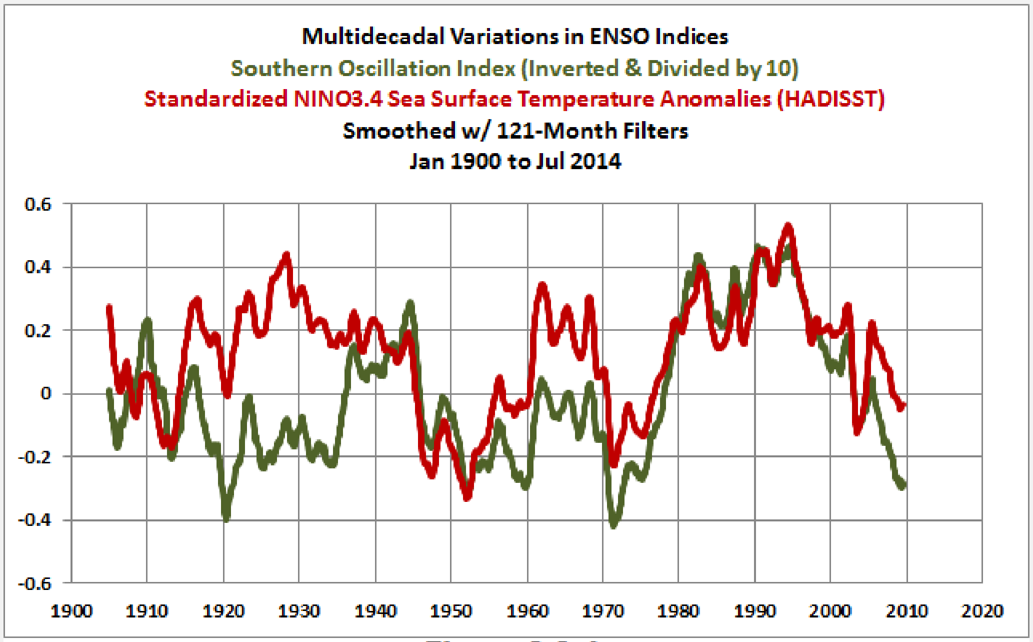


Figure 3.9-4

The BOM Southern Oscillation Index (inverted) shows a stronger tendency toward La Niña in recent years. The Southern Oscillation Index also does not make the upswing into El Niño dominance in the 1960s as the NINO3.4 data indicate. There is another major divergence between the two datasets from the mid-1910s to the mid-1930s. Then again, that's when the Southern Oscillation Index and NINO3.4 sea surface temperature data are questionable.

There is a well-established relationship between the Southern Oscillation and El Niño and La Niña events. The data reveal that the long-term Southern Oscillation Index can be out of phase with the sea surface temperature-based ENSO indices. Some of the difference is, again, caused by the off-equator locations of the measurements for the Southern Oscillation Index, and some of the difference can result from the integrity of the data.

Again, for a more detailed discussion of the Southern Oscillation, refer to Chapter 3.7, under the heading of THE SOUTHERN OSCILLATION INDEX.

3.10 – Atmospheric Mode – North Atlantic Oscillation (NAO)

There are two ways to determine the indices that represent the North Atlantic Oscillation. We'll discuss them both in this chapter.

The North Atlantic Oscillation is a sea level pressure-derived index over the North Atlantic, which means it reflects changes in wind patterns there. It impacts how much and where heat is transported from the tropics to the high latitudes of the Northern Hemisphere in and near the North Atlantic basin. The North Atlantic Oscillation also has a strong impact on the ocean heat uptake of the North Atlantic and has been linked to the Atlantic Multidecadal Oscillation.

NORTH ATLANTIC OSCILLATION BASED ON SEA LEVEL PRESSURE DIFFERENCES BETWEEN TWO LOCATIONS

One of the North Atlantic Oscillation datasets is based on the difference between sea level pressures in two locations. For the North Atlantic Oscillation data, sea level pressures are sensed at high and mid latitudes of land masses within or near the North Atlantic, but the actual locations can differ between datasets. The NOAA National Centers for Environmental Information (NCEI, formerly the NCDC) has a description of it on their North Atlantic Oscillation (NAO) webpage. The following are the first few paragraphs:

> *The North Atlantic Oscillation (NAO) index is based on the surface sea-level pressure difference between the Subtropical (Azores) High and the Subpolar Low. The positive phase of the NAO reflects below-normal heights and pressure across the high latitudes of the North Atlantic and above-normal heights and pressure over the central North Atlantic, the eastern United States and western Europe. The negative phase reflects an opposite pattern of height and pressure anomalies over these regions. Both phases of the NAO are associated with basin-wide changes in the intensity and location of the North Atlantic jet stream and storm track, and in large-scale modulations of the normal patterns of zonal and meridional heat and moisture transport, which in turn results in changes in temperature and precipitation patterns often extending from eastern North America to western and central Europe.*

> *Strong positive phases of the NAO tend to be associated with above-normal temperatures in the eastern United States and across northern Europe and below-normal temperatures in Greenland and oftentimes across southern Europe and the Middle East. They are also associated with above-normal precipitation over northern Europe and Scandinavia and below-normal precipitation over southern and central Europe. Opposite patterns of temperature and precipitation*

> *anomalies are typically observed during strong negative phases of the NAO. During particularly prolonged periods dominated by one particular phase of the NAO, abnormal height and temperature patterns are also often seen extending well into central Russia and north-central Siberia. The NAO exhibits considerable interseasonal and interannual variability, and prolonged periods (several months) of both positive and negative phases of the pattern are common.*

The NCEI used the terms zonal and meridional in their overview. Zonal refers to east-west directions, and meridional to north-south. So their one sentence in the first paragraph could be re-written as, *Both phases of the NAO are associated with basin-wide changes in the intensity and location of the North Atlantic jet stream and storm track, and in large-scale modulations of the normal patterns of* east-west (west-east) and north-south (south-north) *heat and moisture transport*…

In other words, the variations in the sea level pressures at high and mid latitudes in the North Atlantic impact how much and where heat is transported from the tropics to the high latitudes of the Northern Hemisphere in and near the North Atlantic basin.

The North Atlantic Oscillation or NAO is commonly referred to by European meteorologists during their local weather discussions.

There are two long-term North Atlantic Oscillation datasets on the Monthly climate indices webpage at the KNMI Climate Explorer. Both are from the Climatic Research Unit (CRU) at the University of East Anglia and they are based on the paper Jones et al (1997) Extension to the North Atlantic Oscillation using early instrumental pressure observations from Gibraltar and South-West Iceland. Also see the CRU webpage here, where they define the North Atlantic Oscillation data:

> The NAO is traditionally defined as the normalized pressure difference between a station on the Azores and one on Iceland. An extended version of the index can be derived for the winter half of the year by using a station in the southwestern part of the Iberian Peninsula (Hurrell, 1995). Here we give data for SW Iceland (Reykjavik), Gibraltar and Ponta Delgada (Azores). The NAO calculated from Gibraltar and SW Iceland is also given (Jones et al., 1997).

The one based on data from Iceland and Gibraltar starts in 1821 and is updated regularly at the KNMI Climate Explorer, and the North Atlantic Oscillation data from Iceland and the Azores starts in 1865 and ends in 2002. Both datasets have been standardized. Using 121-month running-average filters, both versions of the North Atlantic Oscillation data are compared in Figure 3.10-1. There are quite a few dissimilarities between the two datasets, with differences in the magnitudes of the decadal and multidecadal variations and the timings of their crossing zero. Is one right and the other wrong? With the common reference of Iceland, they're based on the sea level pressures at two locations that are separated by about 1800 km (1125 miles), so they could both very well be correct.

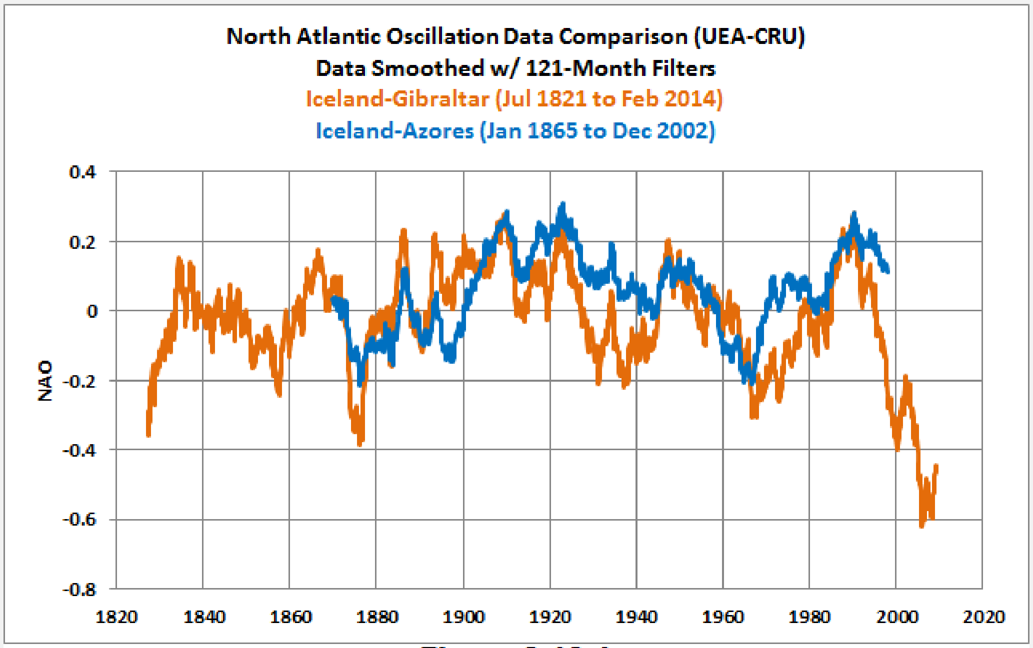


Figure 3.10-1

The sharp decline in the Gibraltar data since the late 1990s looks ominous, but it does not appear in another version of the North Atlantic Oscillation data (as shown later in this chapter in Figure 3.10-8), so it's a peculiarity of this version.

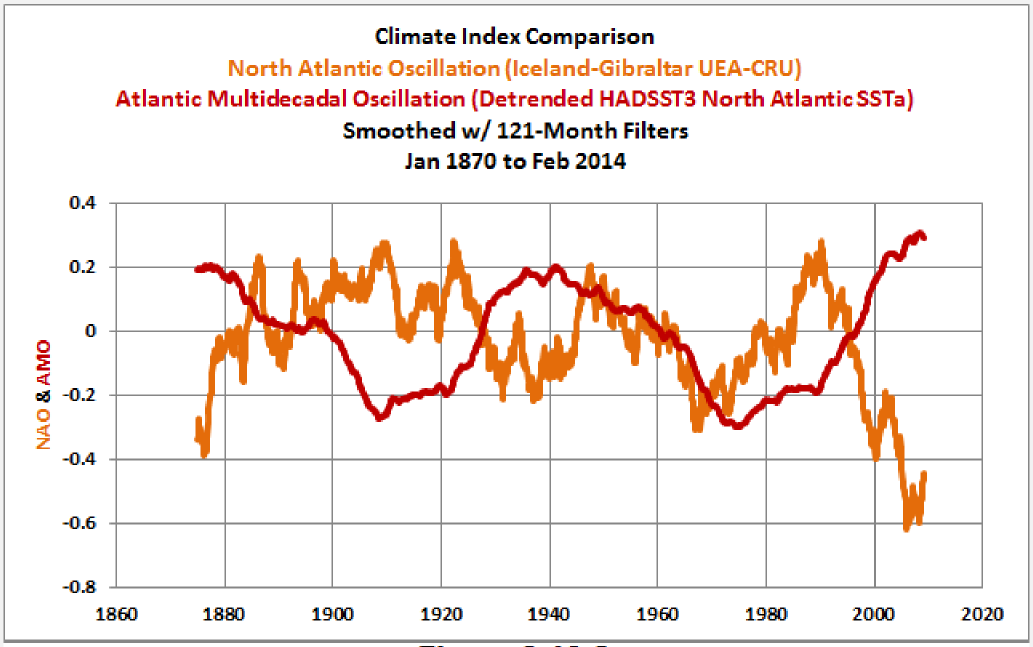


Figure 3.10-2

The North Atlantic Oscillation data and the Atlantic Multidecadal Oscillation data (using detrended North Atlantic sea surface temperature anomalies) are compared in Figure 3.10-2, with both datasets smoothed with 121-month filters. There appears to be some agreement between the two datasets, from the late 1940s to the late 1960s, and then, after being out of synch for a decade, they temporarily realign from the late 1970s to about 1990. A relationship looks questionable.

Interestingly, if we invert the North Atlantic Oscillation data, they seem to align with the Atlantic Multidecadal Oscillation data during other time periods. See Figure 3.10-3. There is a tendency for the North Atlantic Oscillation data to follow the same underlying curve as the Atlantic Multidecadal Oscillation data prior to the early 1940s and after 1990, but they are generally out of phase from the early 1940s until the 1990s. As a reference, I presented another version of the Atlantic Multidecadal Oscillation (North Atlantic sea surface temperature anomalies minus the data for the rest of the global oceans) in Figure 3.10-4. Again, a relationship looks questionable.

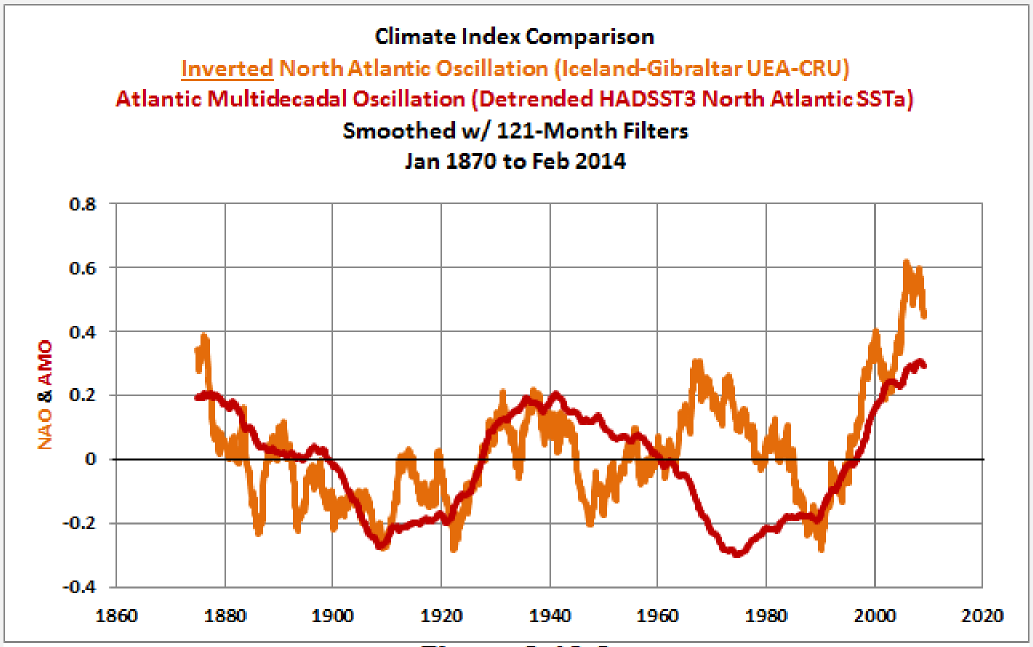


Figure 3.10-3

# # #

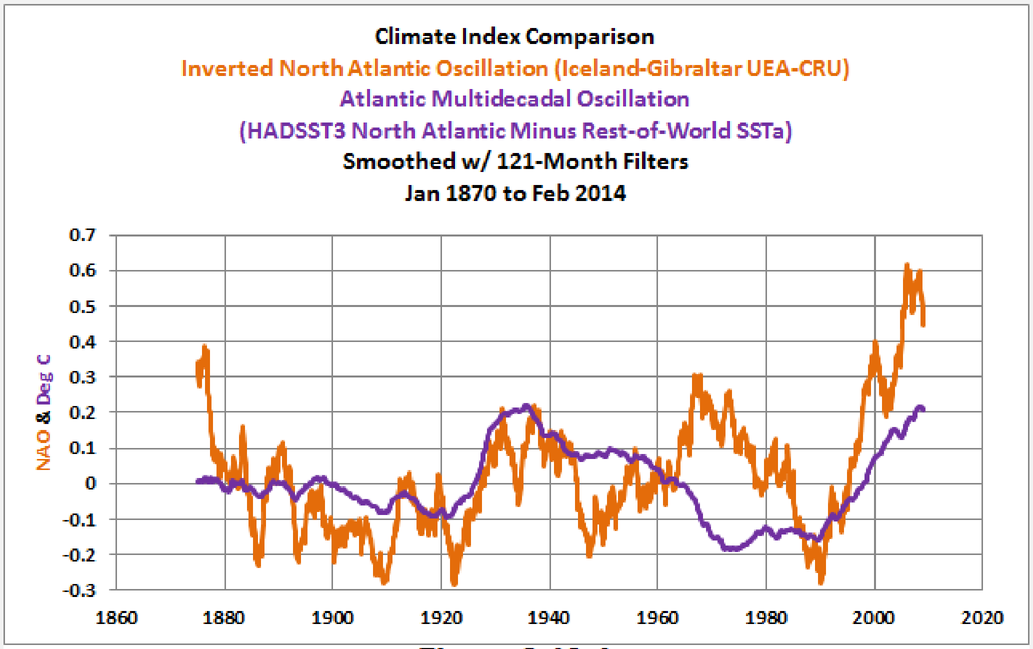
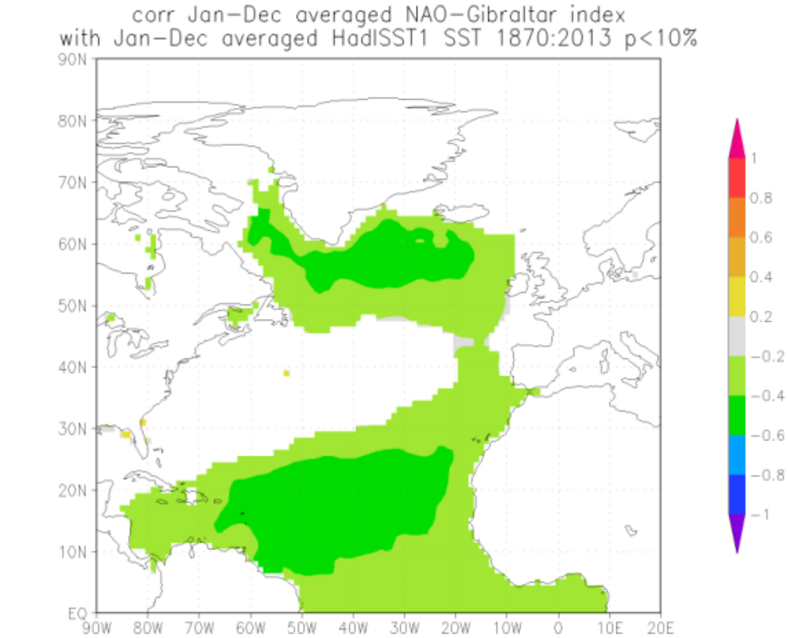


Figure 3.10-4

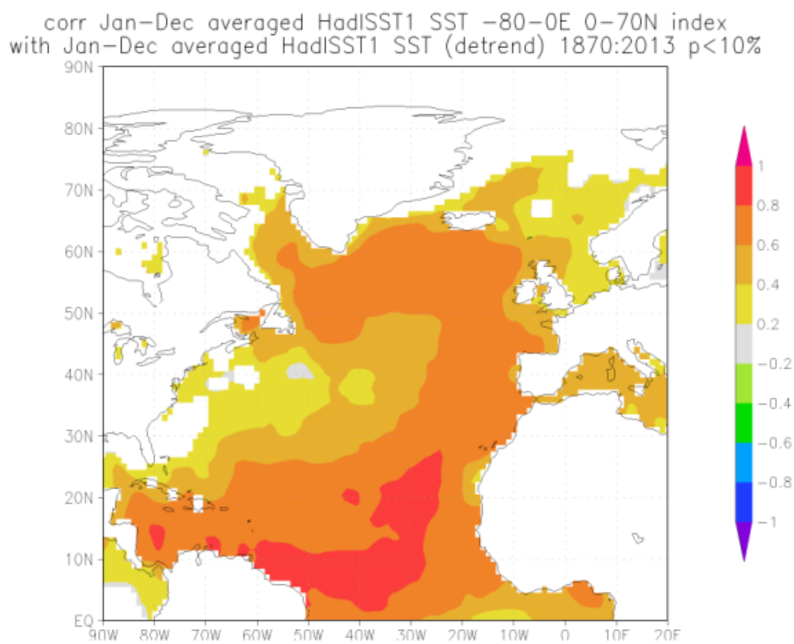
You'll also find papers that discuss the similar spatial patterns in the sea surface temperatures of the North Atlantic based on the North Atlantic Oscillation and the Atlantic Multidecadal Oscillation. See the correlation maps in Figure 3.10-5. The spatial pattern is often referred to as a "tripole" in those studies, where correlations with the sea surface temperatures east of the southeast United States are different than those in the tropical North Atlantic and east of Canada.

Correlation of Indices with
Annual North Atlantic Sea Surface Temperature Anomalies
(1870 to 2013)

North Atlantic Oscillation
(Iceland-Gibraltar)



Atlantic Multidecadal Oscillation
(Detrended North Atlantic SSTa)



Maps Created at KNMI Climate Explorer

Figure 3.10-5

McCarthy et al. (2015) Ocean impact on decadal Atlantic climate variability revealed by sea-level observations found that the Atlantic Multidecadal Oscillation is linked with the North Atlantic Oscillation. The abstract reads (my boldface):

> *Decadal variability is a notable feature of the Atlantic Ocean and the climate of the regions it influences. Prominently, this is manifested in the Atlantic Multidecadal Oscillation (AMO) in sea surface temperatures. Positive (negative) phases of the AMO coincide with warmer (colder) North Atlantic sea surface temperatures. The AMO is linked with decadal climate fluctuations, such as Indian and Sahel rainfall[1], European summer precipitation[2], Atlantic hurricanes[3] and variations in global temperatures[4]. It is widely believed that ocean circulation drives the phase changes of the AMO by controlling ocean heat content[5]. However, there are no direct observations of ocean circulation of sufficient length to support this, leading to questions about whether the AMO is controlled from another source[6]. Here we provide observational evidence of the widely hypothesized link between ocean circulation and the AMO. We take a new approach, using sea level along the east coast of the United States to estimate ocean circulation on decadal timescales.* ***We show that ocean circulation responds to the first mode of Atlantic atmospheric forcing, the North Atlantic Oscillation, through circulation changes between the subtropical and subpolar gyres—the intergyre region[7]. These circulation changes affect the decadal evolution of North Atlantic heat content and, consequently, the phases of the AMO.*** *The Atlantic overturning circulation is declining[8] and the AMO is moving to a negative phase. This may offer a brief respite from the persistent rise of global temperatures[4], but in the coupled system we describe, there are compensating effects. In this case, the negative AMO is associated with a continued acceleration of sea-level rise along the northeast coast of the United States[9, 10].*

So far in this chapter I’ve only presented the North Atlantic Oscillation data smoothed with 121-month filters. The “raw” monthly data from 1979 to present are shown in Figure 3.10-6. They are very volatile, with wide sings from month to month.

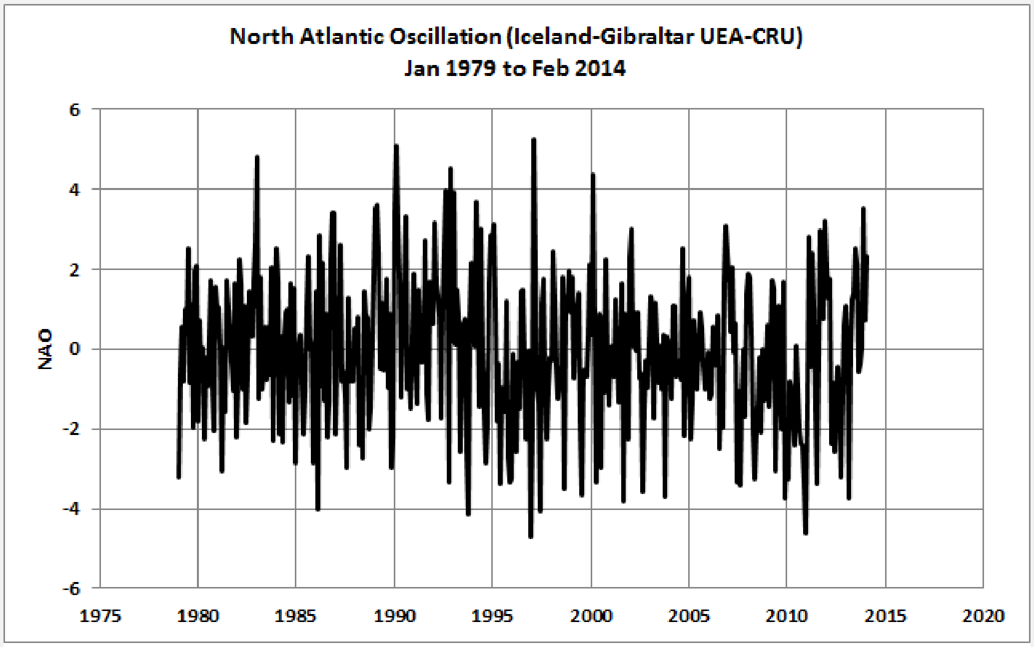


Figure 3.10-6

# # #

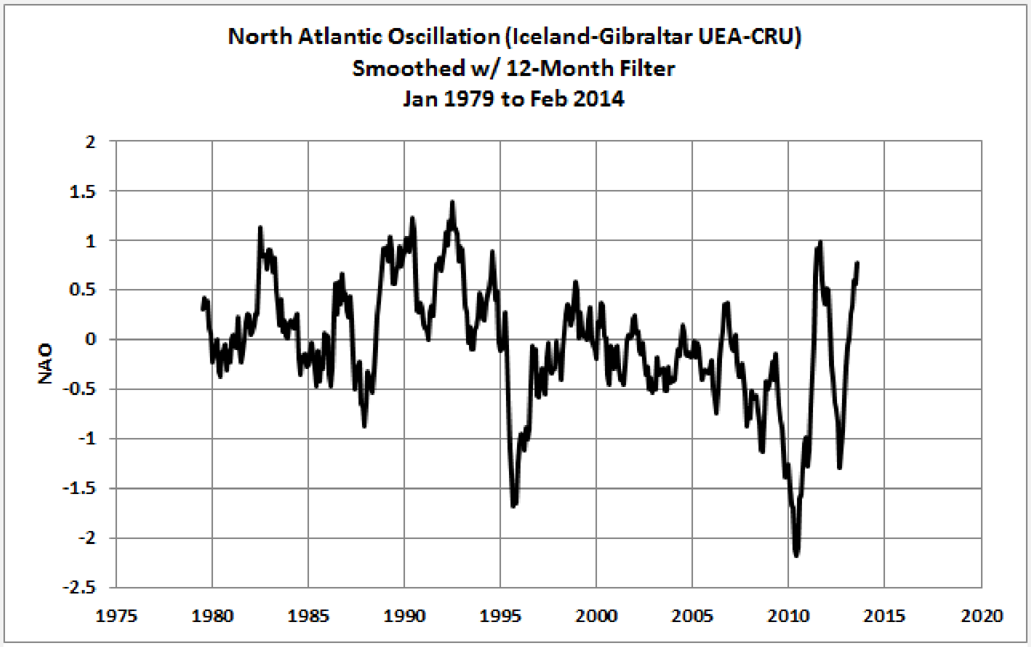


Figure 3.10-7

And the North Atlantic Oscillation data are smoothed with a 12-month filter in Figure 3.10-7, to minimize any seasonal components and weather noise. They are still quite volatile.

NORTH ATLANTIC OSCILLATION BASED ON PRINCIPAL COMPONENT ANALYSIS

Because the North Atlantic Oscillation also relates to the spatial patterns in the sea level pressures of the North Atlantic, the National Center for Atmospheric Research (NCAR) has created a dataset based on principal component analysis and empirical orthogonal function analysis of the sea level pressures of the entire North Atlantic, not just two points. The simplest way to explain those two analyses is that they will determine the dominant spatial pattern of a specific metric (sea level pressure, sea surface temperatures, etc.) and, they'll determine as a time-series how closely the spatial pattern in any specific month matches the dominant spatial pattern.

NCAR provides an overview of the principal component analysis-based North Atlantic Oscillation at their NAO Summary webpage here.   They write:

> *The principal component (PC)-based indices of the North Atlantic Oscillation (NAO) are the time series of the leading Empirical Orthogonal Function (EOF) of SLP anomalies over the Atlantic sector, 20°-80°N, 90°W-40°E. These indices are used to measure the NAO throughout the year, tracking the seasonal movements of the Icelandic low and Azores high. These movements are illustrated in the Figures on this page. Positive values of the NAO index are typically associated with stronger-than-average westerlies over the middle latitudes, more intense weather systems over the North Atlantic and wetter/milder weather over western Europe.*

NCAR lists the two key advantages or strengths of the principal component analysis-based index.

- *PC-based indices are more optimal representations of the full spatial patterns of the NAO*
- *May be less noisy than station-based indices*

And they also list the limitations or disadvantages:

- *Not available as far back as station-based indices*
- *Dependent on any inherent weaknesses in the source data set and its gridding scheme*

Also see the NCAR "Expert Guidance" and other webpages linked to their Hurrell North Atlantic Oscillation (NAO) Index (PC Based) webpage.

NCAR presents their principal component-based North Atlantic Oscillation Index data here. It stretches from January 1899 to present. The NCAR principal component-based and the UEA-CRU Iceland-Gibraltar version of the North Atlantic Oscillation

Index data are compared in Figure 3.10-8. Both datasets are shown from January 1899 to February 2014 and have been smoothed with 121-month running-average filters.

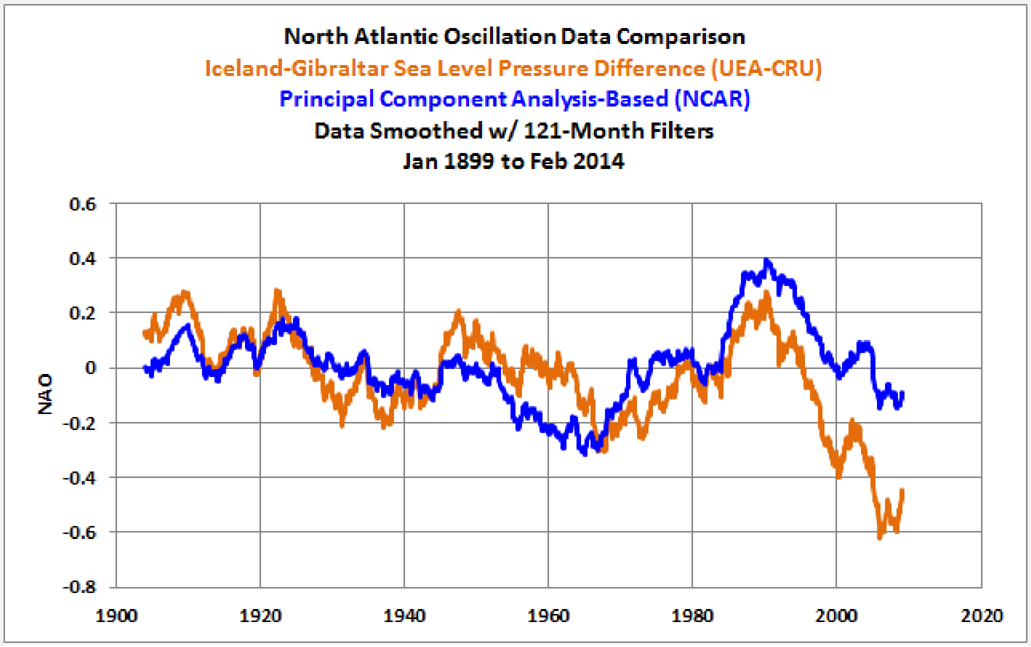


Figure 3.10-8

The NCAR principal component-version does not show the sharp drop-off since the 1990s, and its long-term variations are smaller before the late 1960s and after 1990, but greater from the late 1960s to about 1990.

ON THE IMPORTANCE OF THE NORTH ATLANTIC OSCILLATION

Hurrell and Deser (2008) North Atlantic climate variability: The role of the North Atlantic Oscillation provides an excellent detailed look at the importance of the North Atlantic Oscillation. The second paragraph of the abstract reads:

> *A leading pattern of weather and climate variability over the Northern Hemisphere is the North Atlantic Oscillation (NAO). The NAO refers to a redistribution of atmospheric mass between the Arctic and the subtropical Atlantic, and swings from one phase to another producing large changes in surface air temperature, winds, storminess and precipitation over the Atlantic as well as the adjacent continents. The NAO also affects the ocean through changes in heat content, gyre circulations, mixed layer depth, salinity, high latitude deep water formation and sea ice cover. Thus, indices of the NAO have become widely used to document and understand how this mode of variability alters the structure and functioning of marine ecosystems*.

Depending on the mode, the North Atlantic Oscillation can contribute to long-term regional surface warming or suppress it.

THE NORTH ATLANTIC OSCILLATION ALSO IMPACTS OCEAN HEAT UPTAKE IN THE NORTH ATLANTIC

The North Atlantic Oscillation and the surface wind patterns associated with it also play a role in ocean heat uptake of the North Atlantic. In fact, there is a paper that explains how the warming of the North Atlantic to depths of 700 meters (about 2300 feet) was caused naturally and that the North Atlantic Oscillation played the major role. There are a few curiosities about that paper. One of them was that the authors were not claiming that the additional warming of the North Atlantic to depths of 700 meters was caused naturally; they were discussing how all of the warming there was caused by natural processes…not by man-made greenhouse gases.

That paper was Lozier et al. (2008) The Spatial Pattern and Mechanisms of Heat-Content Change in the North Atlantic. We discussed Lozier et al. in Chapter 1.15. Let's repeat that discussion because it's important.

TALE OF THE DATA: THE WARMING OF THE NORTH ATLANTIC TO DEPTH

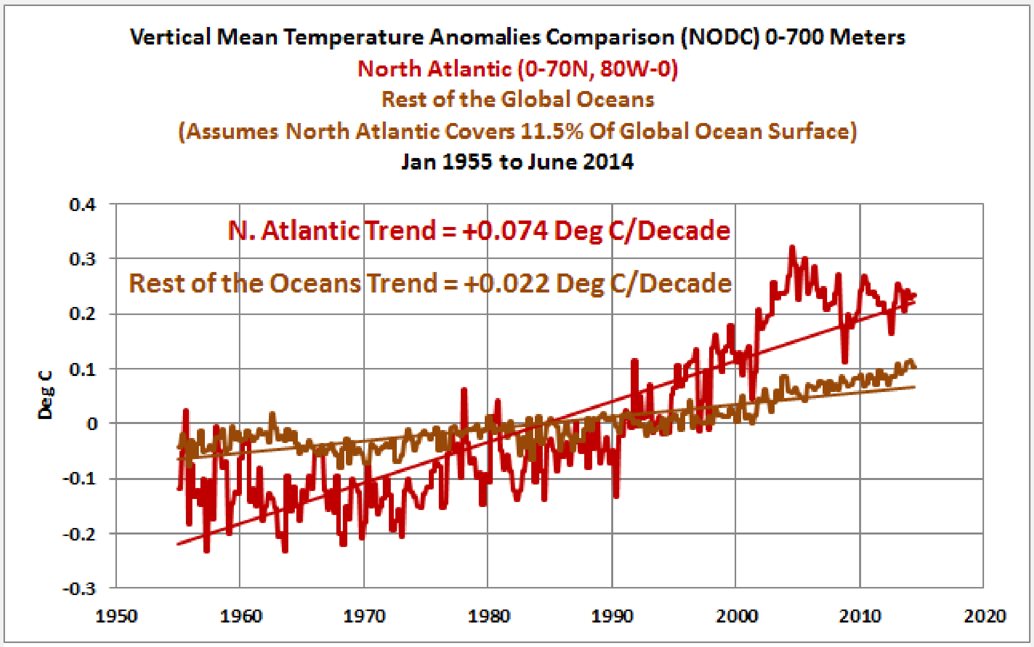


Figure 3.10-9

As a preface, Figure 3.10-9 presents the depth-averaged temperature anomalies (0-700 meters) for the North Atlantic and for the rest of the global oceans. To determine the depth-averaged temperature anomalies for the rest of the global oceans, I area-weighted the North Atlantic data (11.5%, see the NOAA webpage here) and subtracted the result of the weighting from the global data. The units are deg C.

It very obvious that the North Atlantic to depths of 700 meters warmed at a much faster rate than the rest of the oceans, about 3.3 times faster from 1955 to present. That ocean basin only covers 11.5% of the surface of the global oceans, yet it represents about 35% of the ocean warming to depths of 700 meters. Now consider that all the warming of the North Atlantic is considered in one climate study to have occurred naturally, not from man-made greenhouse gases. Using global ocean heat content as a proxy for radiative imbalance caused by man-made greenhouse gases is then obviously flawed.

NOTE: It is unfortunate that the outputs of the climate model simulations of depth averaged temperature (or ocean heat content) are not available in an easy-to-use form so that the models can be compared to observations. We know climate models do not properly simulate the warming of ocean surfaces. They double the warming rate of the ocean surfaces over the past 33 years. See the model-data comparison graph here. Also see the posts here and here for additional discussions. It would be interesting to see how poorly the models simulate ocean warming to depth. [End note.]

It's very obvious why the change in the ocean heat content is very important to the hypothesis of human-induced global warming. If the oceans could be shown to have warmed naturally, then the impacts of man-made greenhouse gases are much smaller than claimed by climate scientists.

And that's exactly what a group of scientists did back in 2008. They determined the warming of the North Atlantic to 700 meters since 1955 was caused by naturally occurring processes, not by man-made greenhouse gases. We've discussed this paper a few times in recent years—in blog posts and in books. Here's a portion of my ebook *Who Turned on the Heat?* I've updated it for this text.

[START OF REPRINT FROM *WHO TURNED ON THE HEAT?*]

There is a study that provides an explanation for that additional warming. See Lozier et al (2008) The Spatial Pattern and Mechanisms of Heat-Content Change in the North Atlantic.

First, a quick introduction to one of the terms used in the following quotes: The North Atlantic Oscillation is an atmospheric climate phenomenon in the North Atlantic. The North Atlantic Oscillation is expressed as the sea level pressure difference between two points. The sea level pressures in Iceland, at the weather stations in Stykkisholmur or Reykjavik, can be used to calculate North Atlantic Oscillation Indices. Which Iceland location they elect to use as the high-latitude sea level pressure reference depends on the dataset supplier. The other point captures the sea level pressure at the mid-latitudes of the North Atlantic, and there are a number of locations that have been used for it: Lisbon, Portugal; Ponta Delgada, Azores; and Gibraltar. The North Atlantic Oscillation Index is primarily used for weather prediction. The direction and strength of the westerly winds in the North Atlantic are impacted by the sea level pressures in

Iceland and the mid-latitudes of the North Atlantic, which, in turn, impact weather patterns in Europe and the East Coast of North America. If you live in those locations, you'll often hear your weather person referring to the North Atlantic Oscillation. As will be discussed, winds in the North Atlantic can also impact Ocean Heat Content.

I'll present two quotes from the Lozier et al (2008) paper. I'll follow them with quotes from the press release that describes in layman terms how the North Atlantic Oscillation impacts the Ocean Heat Content of the North Atlantic. Back to Lozier et al (2008):

The abstract reads:

> *The total heat gained by the North Atlantic Ocean over the past 50 years is equivalent to a basinwide increase in the flux of heat across the ocean surface of 0.4 ± 0.05 watts per square meter. We show, however, that this basin has not warmed uniformly: Although the tropics and subtropics have warmed, the subpolar ocean has cooled. These regional differences require local surface heat flux changes (±4 watts per square meter) much larger than the basinwide average. Model investigations show that these regional differences can be explained by large-scale, decadal variability in wind and buoyancy forcing as measured by the North Atlantic Oscillation index. Whether the overall heat gain is due to anthropogenic warming is difficult to confirm because strong natural variability in this ocean basin is potentially masking such input at the present time.*

In the paper, Lozier et al (2008) note, using NAO for North Atlantic Oscillation:

> *A comparison of the zonally integrated heat-content changes as a function of latitude (Fig. 4B) confirms that the NAO difference can largely account for the observed gyre specific heat-content changes over the past 50 years, although there are some notable differences in the latitudinal band from 35° to 45°N. Thus, we suggest that the large-scale, decadal changes in wind and buoyancy forcing associated with the NAO is primarily responsible for the ocean heat-content changes in the North Atlantic over the past 50 years.*

Based on the wording of the two quotes, the paper appears to indicate that Lozier et al (2008) are describing the entire warming of ocean heat content in the North Atlantic. In other words, it seems that Lozier et al (2008) are not stating that the North Atlantic Oscillation is primarily responsible for the additional ocean heat-content changes in the North Atlantic, above and beyond the rest of the world, over the past 50 years; they're saying it's primarily responsible for all of the variability. The press release for the paper, on the other hand, leads you to believe the North Atlantic Oscillation is responsible for the North Atlantic warming above and beyond the global warming.

The Duke University press release for the paper is titled North Atlantic Warming Tied to Natural Variability. Though the other ocean basins weren't studied by Lozier et al, the subtitle of the press release includes the obligatory reference to an assumed man-made warming in other basins: "But global warming may be at play elsewhere in the world's oceans, scientists surmise". To contradict that, we've found no evidence of an anthropogenic component in the warming of the other ocean basins, ~~as will be discussed in a few moments~~. (Refer back to Chapter 1.15.)

The press release reads with respect to the North Atlantic Oscillation (NAO):

> *Winds that power the NAO are driven by atmospheric pressure differences between areas around Iceland and the Azores. "The winds have a tremendous impact on the underlying ocean," said Susan Lozier, a professor of physical oceanography at Duke's Nicholas School of the Environment and Earth Sciences who is the study's first author.*

Further to this, they write:

> *Her group's analysis showed that water in the sub-polar ocean—roughly between 45 degrees North latitude and the Arctic Circle—became cooler as the water directly exchanged heat with the air above it.*
>
> *By contrast, NAO-driven winds served to "pile up" sun-warmed waters in parts of the subtropical and tropical North Atlantic south of 45 degrees, Lozier said. That retained and distributed heat at the surface while pushing underlying cooler water further down.*
>
> *The group's computer model predicted warmer sea surfaces in the tropics and subtropics and colder readings within the sub-polar zone whenever the NAO is in an elevated state of activity. Such a high NAO has been the case during the years 1980 to 2000, the scientists reported.*
>
> *"We suggest that the large-scale, decadal changes...associated with the NAO are primarily responsible for the ocean heat content changes in the North Atlantic over the past 50 years," the authors concluded.*

[END OF REPRINT FROM *WHO TURNED ON THE HEAT?*]

"…SOME STATE OF THE ART CLIMATE MODELS ARE UNABLE TO CORRECTLY SIMULATE THE PHYSICAL PROCESSES CONNECTED TO THE NAO…"

The quote above is from the abstract of Davini and Cagnazzo (2013) On the misinterpretation of the North Atlantic Oscillation in CMIP5 models. Unfortunately, the paper is paywalled so we don't know which of the models stored in the CMIP5 archive are considered by Davini and Cagnazzo to be state-of-the-art. The abstract reads (My boldface):

> *The representation of the wintertime North Atlantic Oscillation (NAO) and its relationship with atmospheric blocking and the Atlantic jet stream is investigated in a set of CMIP5 models.* ***It is shown that some state-of-the-art climate models are unable to correctly simulate the physical processes connected to the NAO.*** *This is especially true for models with a strongly underestimated frequency of high-latitude blocking over Greenland. In these models the first empirical orthogonal function (EOF1) of the Euro-Atlantic sector can represent at least three different categories of dominant modes of variability associated with different prevalent regions of blocking occurrence and jet stream displacements. It is therefore possible to show that such "biased NAOs" are connected with different dynamical processes with respect to the canonical NAO seen in observations. Since the NAO is a widely used concept in scientific community, the consequent "dynamical misinterpretation" of the NAO that can result when climate models are analyzed may have important implications for the NAO-related studies. This may be especially relevant for the ones involving climate scenarios, since these modeled NAOs may react differently to greenhouse gas forcing.*

CHAPTER SUMMARY

The North Atlantic Oscillation index is derived from sea level pressures over the North Atlantic, which means it reflects changes in wind patterns there.

By influencing how much and where heat is transported from the tropics to the high latitudes in and near the North Atlantic basin, the North Atlantic Oscillation logically impacts climate in the Northern Hemisphere. The North Atlantic Oscillation has impacts on ocean heat uptake in the North Atlantic, sea surface temperatures, gyre circulations, mixed layer depth, salinity, high latitude deep water formation and sea ice cover. Too bad that many of the state-of-the-art climate models still do not properly simulate its effects.

3.11 – Atmospheric Mode - North Pacific Index (NPI)

The North Pacific Index is another sea level pressure-based metric. But instead of using the sea level pressures from two locations and determining the differences (like the Southern Oscillation Index and a version of the North Atlantic Oscillation index), the North Pacific Index is the average sea level pressure of a portion of the central extratropical North Pacific. See Figure 3.11-1.

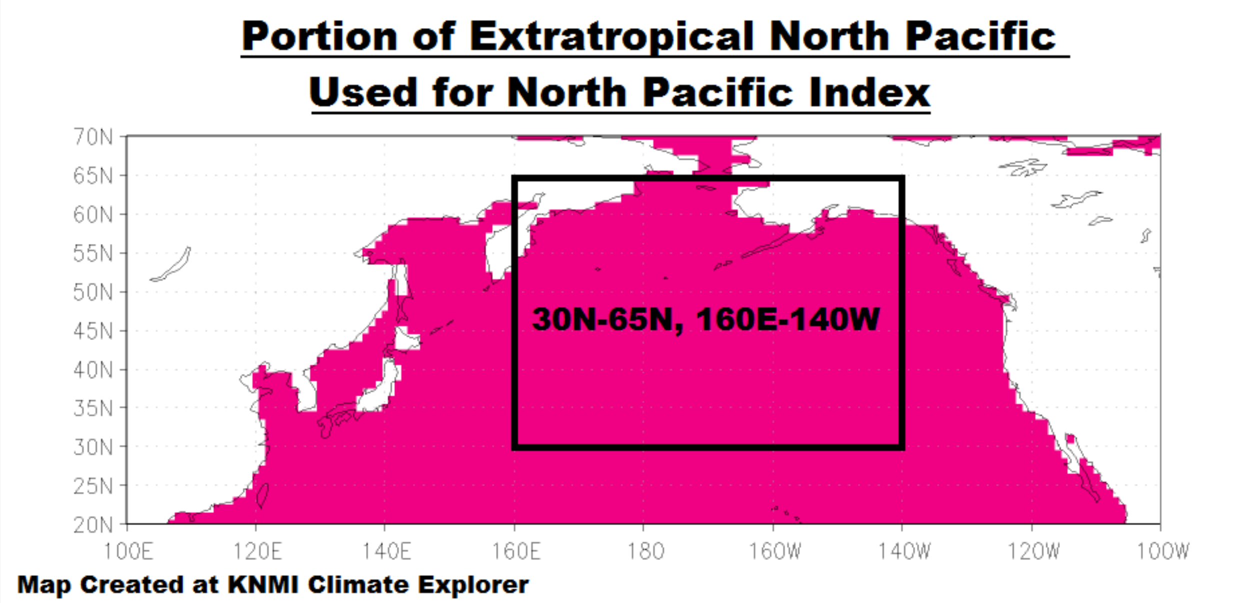


Figure 3.11-1

The North Pacific Index is based on the 1994 paper by Trenberth and Hurrell Decadal atmosphere-ocean variations in the Pacific. Refer also to the webpage at NCAR titled North Pacific (NP) Index by Trenberth and Hurrell; monthly and winter. There they write (my boldface):

> *The North Pacific Index (NP index or NPI) is the area-weighted sea level pressure over the region 30°N-65°N, 160°E-140°W. The NP index is defined to measure interannual to decadal variations in the atmospheric circulation. The dominant atmosphere-ocean relation in the North Pacific is one where* ***atmospheric changes lead changes in sea surface temperatures by one to two months**. **However, strong ties exist with events in the tropical Pacific, with changes in tropical Pacific SSTs leading SSTs in the north Pacific by three months.***

While spatial patterns of temperature and precipitation were also discussed, Trenberth and Hurrell also created the North Pacific Index to help explain why surface temperatures of the North Pacific warmed some decades, remained flat in others and cooled during yet others.

Now, you may be wondering how changes in sea level pressure can influence sea surface temperatures. Changes in sea level pressure reflect changes in wind patterns, and wind patterns can influence where surface temperatures warm and where they cool. Sea level pressures are also related to cloud cover, which varies that amount of sunlight reaching the ocean surface. We discussed this in more detail in Chapter 3.7 – Ocean Mode: El Niño and La Niña with respect to the changes in sea surface temperatures in the tropical Pacific in response to El Niño and La Niña events. Additionally, wind patterns can resist or enhance the poleward migration of warm waters from the tropics to mid-latitudes. Wind patterns also impact upwelling and downwelling along the coasts.

The monthly North Pacific Index data starting in January 1899 is available from NCAR here in absolute form. Like all sea level pressure based indices, it is extremely volatile. So, for Figure 3.11-2, I've smoothed the North Pacific Index data with a 121-month running-average filter. After the downward step in the 1920s, the North Pacific Index data display decadal and multidecadal variability.

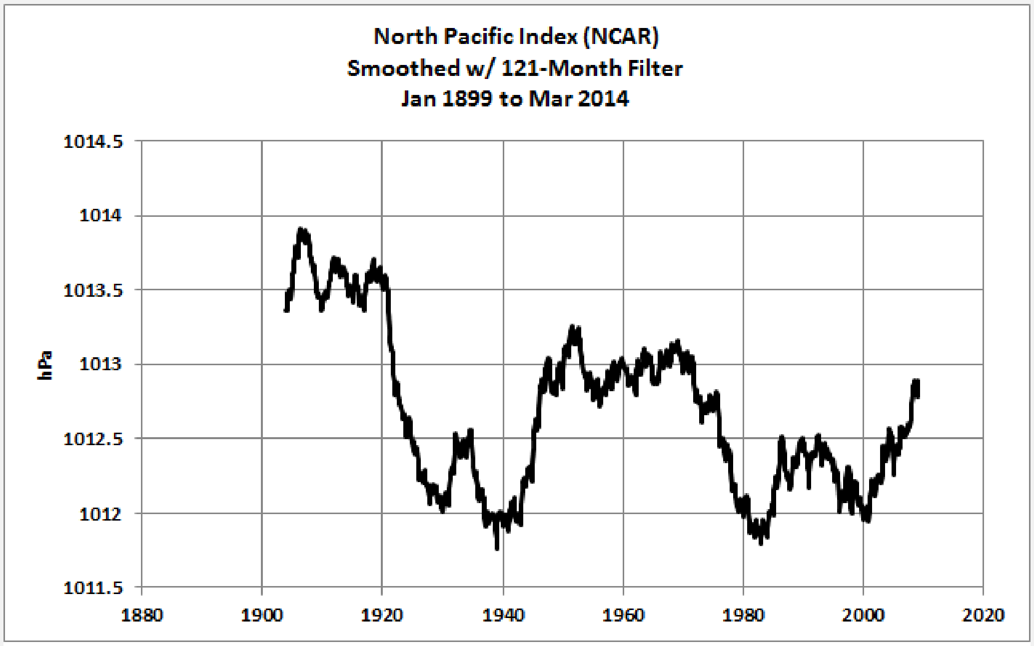


Figure 3.11-2

Note: The units hPa in the y-axis of Figure 3.11-2 are an abbreviation of hectopascal, which means 100 Pascals. A Pascal, in this instance, is a unit of pressure, like pounds per square inch. A Pascal is defined as one (1) Newton per square meter. One (1) hPa is equal to 1 millibar (an older unit of measure). You may be more familiar with another unit of atmospheric pressure, inches of mercury.

Let's compare the North Pacific Index data to the variations in the sea surface temperature of the extratropical North Pacific, using the HADSST3 dataset. By extratropics, we're referring to the portion of the North Pacific that's poleward of the tropics. That is, we're looking at the latitudes of 20N to 65N. We'll smooth both datasets with 121-month filters and arbitrarily scale the sea surface temperature anomaly data so that the scales are similar. As shown in Figure 3.11-3, the multidecadal variations run in and out of synch, making it difficult, at best, to say there's a relationship between the two datasets.

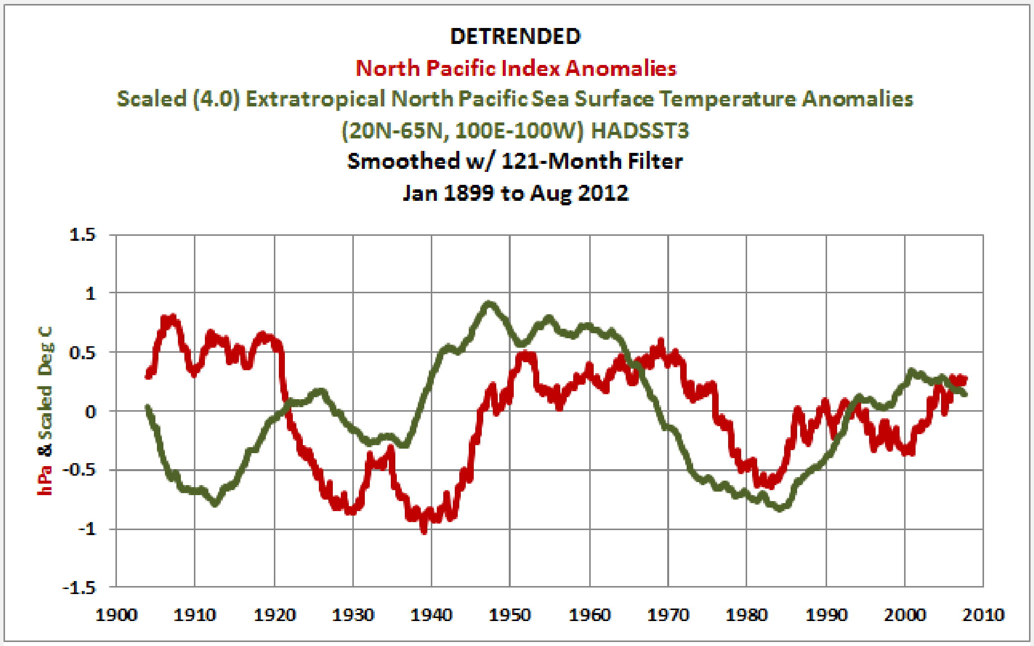


Figure 3.11-3

While there appears to be little agreement between the two datasets, in 1994's Decadal atmosphere-ocean variations in the Pacific, Trenberth and Hurrell used the shifts in the November to March sea level pressures of the North Pacific, based on the North Pacific Index, to explain, in part, a couple of shifts in the sea surface temperatures of the North Pacific. See Figure 3.11-4, which is Figure 6 from Trenberth and Hurrell (1994). They've use average November to March sea level pressures for three periods to highlight the shifts.

Figure 6 from Trenberth and Hurrell (1994)

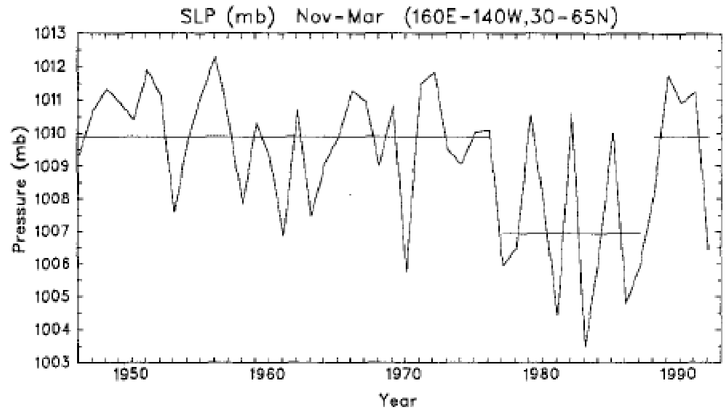


Fig. 6. Time series of mean north Pacific sea level pressures averaged over 30 to 65°N, 160°E to 140°W for the months November through March. Means for 1946–1976 plus 1989–1992 and 1977–1988 are indicated (where 1988 refers to the 1987–88 winter)

Figure 3.11-4

# # #

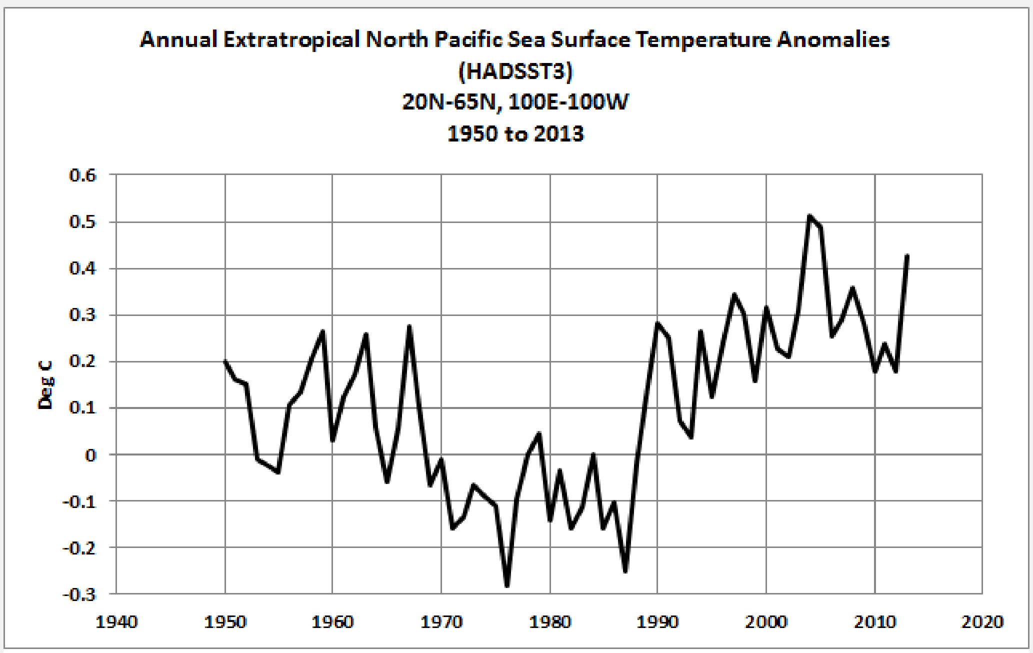


Figure 3.11-5

We can see evidence of similar shifts in the annual sea surface temperature anomalies of the extratropical North Pacific, Figure 3.11-5.

Trenberth and Hurrell (1994) have also introduced us to the concept that seasonal shifts in sea level pressures (and the related wind patterns) can have noticeable impacts on annual sea surface temperatures.

We'll also see evidence of similar shifts in the ocean heat content and depth-averaged temperature data (0-700 meters) in the extratropical North Pacific, which indicates that changes in wind patterns can cause ocean heat uptake. We illustrated and discussed that in more detail in Chapter 1.15 – Can Infrared Radiation from Man-made Greenhouse Gases Warm the Oceans? – And Do the Data Indicate Something Other than Man-made Greenhouse Gases Caused that Warming?

We'll repeat that discussion because it's important.

TALE OF THE DATA: EXTRATROPICAL NORTH PACIFIC

The next paper to be discussed is Trenberth and Hurrell (1994): Decadal Atmosphere-Ocean Variations in the Pacific. In it, Trenberth and Hurrell were using an index derived from the sea level pressures of the extratropical North Pacific (30N-65N, 160E-140W), called the North Pacific Index, to explain shifts in the sea surface temperatures of the North Pacific. Again, a sea level pressure index reflects changes in the wind patterns. My Figure 3.11-4 (above) is Figure 6 from Trenberth and Hurrell (1994).

That same shift appears in the depth-averaged temperature data for the extratropical North Pacific (24N-65N, 120E-80W) for the depths of 0-700 meters. But the shifts are delayed a year in the subsurface temperature data. See Figure 3.11-6 below.

I've color-coded 4 periods on the graph in Figure 3.11-6. The first period from 1955 to 1988 (dark blue) includes the downward shift in 1978. As a result of that shift in 1978 (that should be related to the shift in the sea level pressures and wind patterns), the depth-averaged temperature data show a cooling trend from 1955 to 1988. That is, the extratropical North Pacific to depths of 700 meters cooled (not warmed) for more than 3 decades. The second period (red) captures the upward shift in 1988 and 1989 that, once again, should be related to the shift in the sea level pressures and wind patterns. From 1991 to 2002 (light blue), the extratropical North Pacific cooled once again to depths of 700 meters. And since the ARGO floats were deployed (black), the extratropical Pacific shows a slight warming to depth.

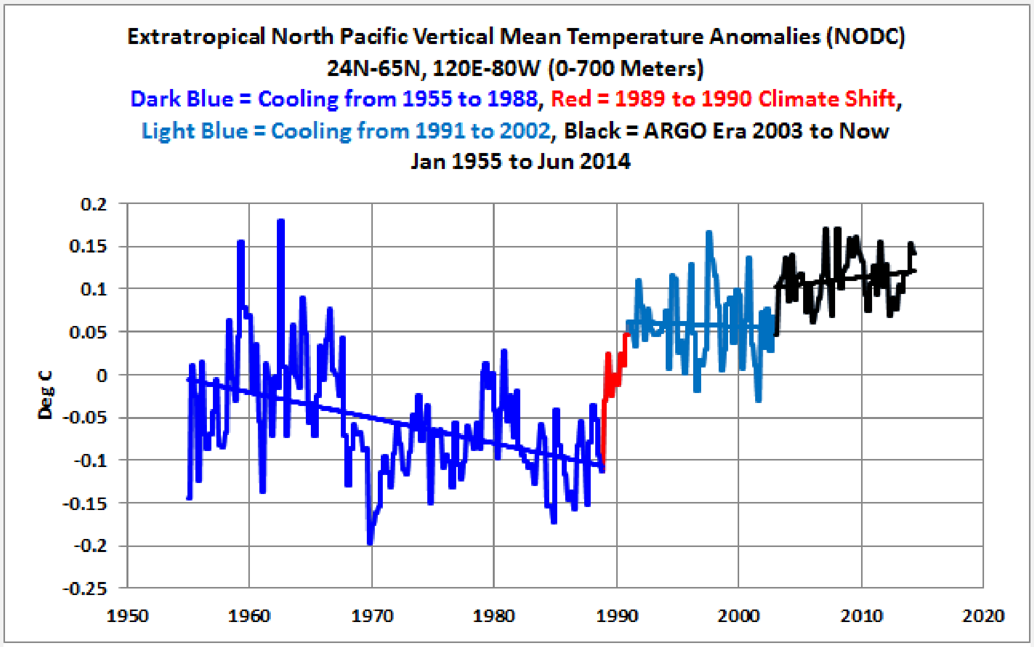


Figure 3.11-6

It's blatantly obvious the extratropical North Pacific to depths of 700 meters would show no warming from 1955 to present if it wasn't for that upward shift in the late 1980s. It's also obvious that the downward shift in 1978 that extends to 1988 also impacts the long-term trend. That is, without the naturally caused downward shift in the late-1970s the long-term warming rate would be less. Obviously, natural variability, not man-made greenhouse gases, dominates the variability and long-term warming of the extratropical Pacific to the depths of 700 meters.

CLOSING

Once again, we're seeing evidence:

- that the oceans and atmosphere are coupled, and
- that changes in the sea level pressure of an ocean basin (and the related wind patterns) can cause ocean warming and cooling for decadal and multidecadal periods even to the depths of an ocean basin.

Of course, the climate models used by the IPCC and other political report-writing entities assume all of the ocean warming was caused by man-made greenhouse gases, even when the data contradict those assumptions.

3.12 – Atmospheric Mode - Arctic Oscillation (AO)

If you live in the Northern Hemisphere, you may recall your local weatherperson mentioning the Arctic Oscillation during a boreal winter forecast. The changes in sea level pressure and wind patterns associated with the Arctic Oscillation can direct cold Arctic air from high latitudes toward more temperate lower latitudes. The Arctic Oscillation also has an impact on Arctic sea ice during the melt season. You have to keep in mind that Arctic sea ice is floating atop the Arctic Ocean and the wind patterns in the Arctic can actually push sea ice out of the Arctic Ocean. More on that in a few moments. First…

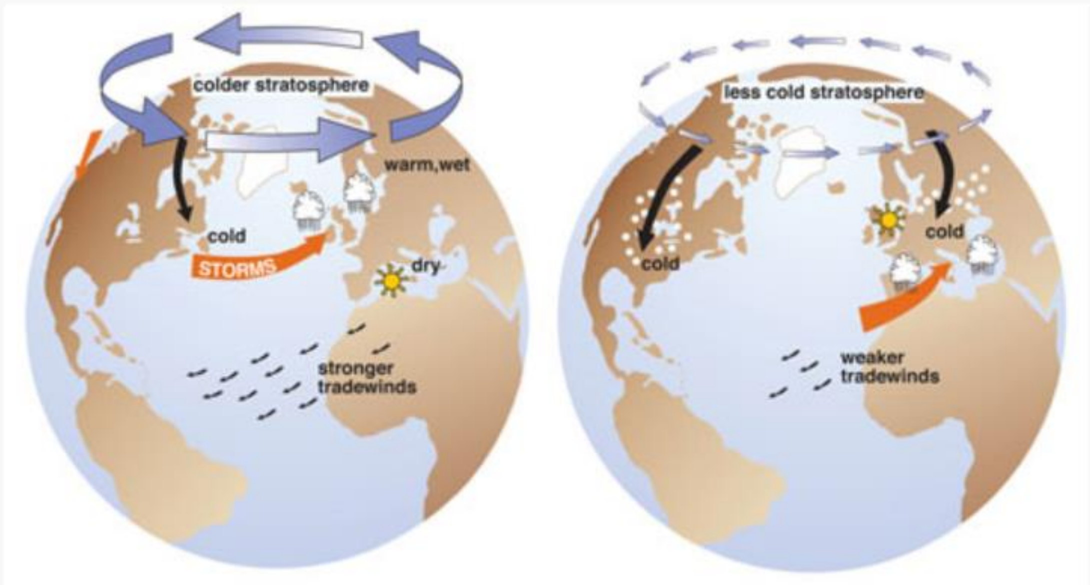
AN OVERVIEW OF THE ARCTIC OSCILLATION

There are a good number of websites that describe the Arctic Oscillation. One of the easiest to understand comes from the National Snow & Ice Data Center (NSIDC), on their Patterns in Arctic Weather and Climate webpage. I've also included one of the illustrations from that webpage as a reference. See Figure 3.12-1. There the NSIDC writes:

> *The **Arctic Oscillation** refers to an opposing pattern of pressure between the Arctic and the northern middle latitudes. Overall, if the atmospheric pressure is high in the Arctic, it tends to be low in the northern middle latitudes, such as northern Europe and North America. If atmospheric pressure is low in the middle latitudes it is often high in the Arctic. When pressure is high in the Arctic and low in mid-latitudes, the Arctic Oscillation is in its negative phase. In the positive phase, the pattern is reversed.*
>
> *Meteorologists and climatologists who study the Arctic pay attention to the Arctic Oscillation, because its phase has an important effect on weather in northern locations. The positive phase of the Arctic Oscillation brings ocean storms farther north, making the weather wetter in Alaska, Scotland, and Scandinavia and drier in the western United States and the Mediterranean. The positive phase also keeps weather warmer than normal in the eastern United States, but makes Greenland colder than normal.*
>
> *In the negative phase of the Arctic Oscillation the patterns are reversed. A strongly negative phase of the Arctic Oscillation brings warm weather to high latitudes, and cold, stormy weather to the more temperate regions where people live. Over most of the past century, the Arctic Oscillation alternated between its positive and negative phase. For a period during the 1970s to mid-1990s, the*

Arctic Oscillation tended to stay in its positive phase. However, since then it has again alternated between positive and negative, with a record negative phase in the winter of 2009-2010.

Arctic Oscillation Illustration from NSIDC Webpage "Patterns in Arctic Weather and Climate"



Left: Effects of the Positive Phase of the Arctic Oscillation.

Right:Effects of the Negative Phase of the Arctic Oscillation. —*Credit: J. Wallace, University of Washington.*

Source: https://nsidc.org/cryosphere/arctic-meteorology/weather_climate_patterns.html

Figure 3.12-1

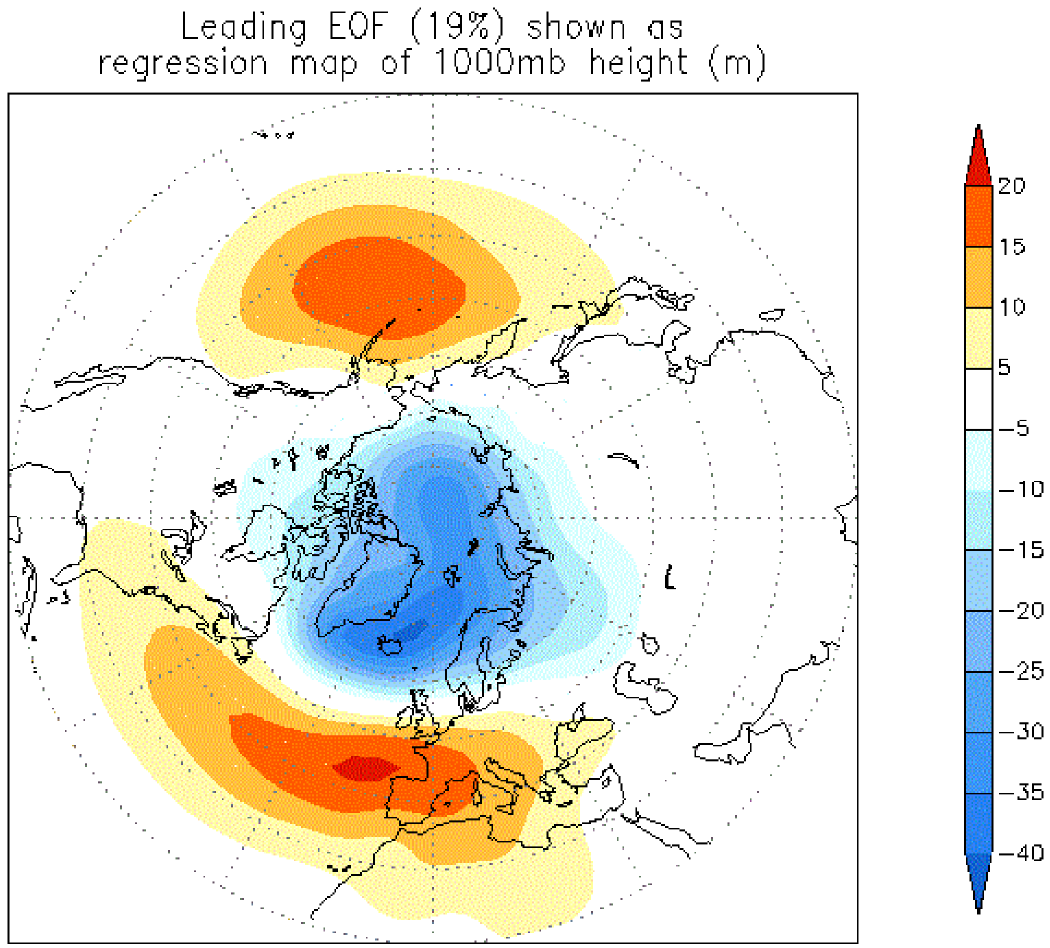
The hyperlink in the quote takes you to the NSIDC glossary webpage for the Arctic Oscillation. It reinforces the above description:

an atmospheric circulation pattern in which the atmospheric pressure over the polar regions varies in opposition with that over middle latitudes (about 45 degrees N) on time scales ranging from weeks to decades; the oscillation extends through the depth of the troposphere, and from January to March, it extends upward into the stratosphere where it modulates in the strength of the westerly vortex that encircles the arctic polar cap region; the north atlantic oscillation and arctic oscillation are different ways of describing the same phenomenon.

THE ARCTIC OSCILLATION INDEX

NOAA CPC

Arctic Oscillation "Loading Pattern"



Source: http://www.cpc.ncep.noaa.gov/products/precip/CWlink/daily_ao_index/loading.html

Figure 3.12-2

The NSIDC's descriptions of the Arctic Oscillation would lead one to suspect that the Arctic Oscillation Index data are prepared like the Southern Oscillation Index. That is, you might think the Arctic Oscillation Index was created by comparing sea level pressures in the Arctic to sea level pressures in the mid-latitudes. In reality, the Arctic Oscillation Index is created using statistical methods that are more similar to those used to create the Pacific Decadal Oscillation (PDO) Index. That is, researchers have determined the dominant spatial pattern of atmospheric pressures in the mid-to-high latitudes (20N-90N) of the Northern Hemisphere. See Figure 3.12-2. Using that statistical analysis, they then compare the spatial pattern for specific time to that dominant spatial pattern. As the match grows closer, the Arctic Oscillation Index value grows higher. If the spatial pattern were to be reversed, with low atmospheric pressures where highs normally exist and with high atmospheric pressures where lows normally exist, the Arctic Oscillation Index values would be negative.

Figure 3.12-2 above presents what the NOAA Climate Prediction Center (CPC) calls the Arctic Oscillation "Loading Pattern". Their description reads:

> *The loading pattern of the AO is defined as the leading mode of Empirical Orthogonal Function (EOF) analysis of monthly mean 1000mb height during 1979-2000 period.*

Further explanations of how the Arctic Oscillation Index is calculated can be found on the following NOAA CPC Teleconnections Pattern Calculation Procedure webpage. Also see Thompson and Wallace (2000) Annular modes in the extratropical circulation. Part I: Month-to-month variability.

THE ARCTIC OSCILLATION INDEX DATA

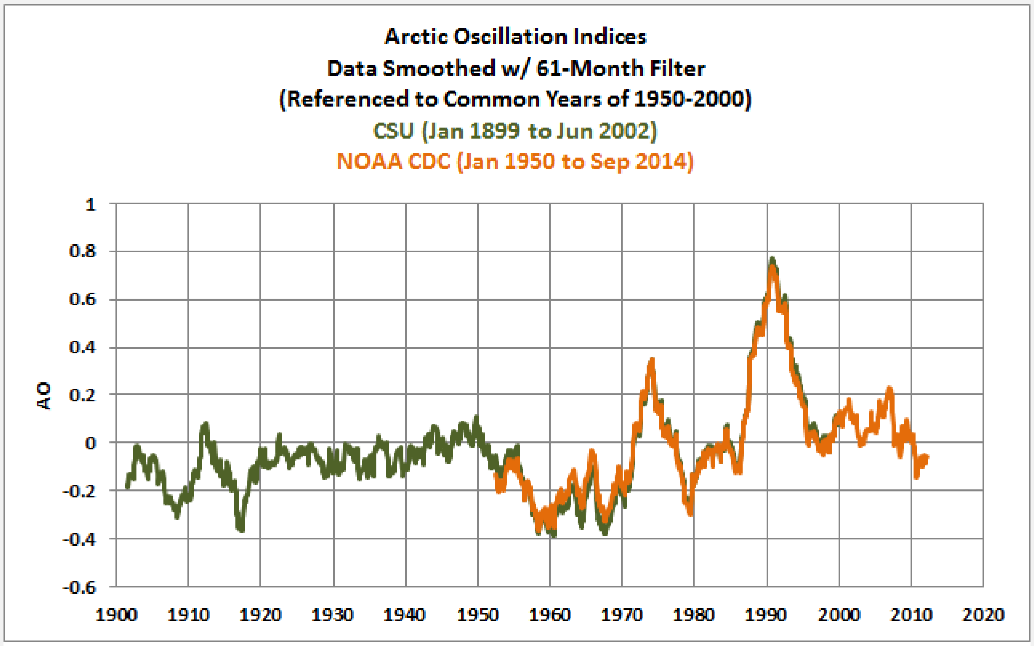


Figure 3.12-3

Arctic Oscillation Index data are available from a number of sources:

1. There is a longer-term monthly dataset available from Colorado State University. It begins in January 1889 and ends in June 2002, so it is not maintained and does not run to current times. The source page is here. The data are here, without a listing of corresponding months.

2. Colorado State University also has another long-term dataset (January to March only) that runs from 1851 to 1997—also not maintained. The data are here.
3. The NOAA Climate Prediction Center (CPC) maintains a monthly Arctic Oscillation Index dataset that begins in January 1950 and runs to the most recent month. The source NOAA CPC webpage is here, and the data in ascii format is here.

Figure 3.12-3 compares the two monthly datasets. The Colorado State University data runs from January 1889 to June 2002, and the NOAA CPC data begin in January 1950 and end in September 2014. I referenced both datasets to their common overlap period of January 1950 to June 2002 and smoothed both datasets with 61-month running-mean filters to minimize the volatility. The two datasets agree with one another for the most part during the overlap period.

The curious spike in the late-1980s to 1990 stands out, that's for sure. There were two possible reasons for it proposed in Maslowski et al. On Large Scale Shifts in the Arctic Ocean and Sea Ice Conditions during 1979-1998. There they write:

> *Two possible explanations of the cyclonic regime shift in the late 1980s / early 1990s can be suggested. One relates the changes in the sea ice and the upper ocean circulation to an increased northward heat flux due to higher temperatures and/or stronger northward transport of Atlantic Water carried from the North Atlantic into the Arctic Ocean. This hypothesis assigns the primary source of the changes in the Arctic Ocean to variability of the global ocean thermohaline circulation, which in our experiment we define as originating in the region outside the model domain. The other possible cause of the cyclonic regime shift in the ice-ocean system in the early 1990s involves variability of the "local" weather patterns over the northern polar region, as determined by one (AO) or possibly more principal modes of atmospheric variability. Major uncertainties remain about the role of ice-ocean processes that feed back to the arctic atmosphere and how these interactions influence arctic climate and its interannual to decadal variability.*

Their model findings suggested it was the latter "local" weather explanation.

To put that spike into perspective, Figure 3.12-4 shows the smoothed and "raw" monthly data. There appears to have been a return toward negative Arctic Oscillation Index values in recent years.

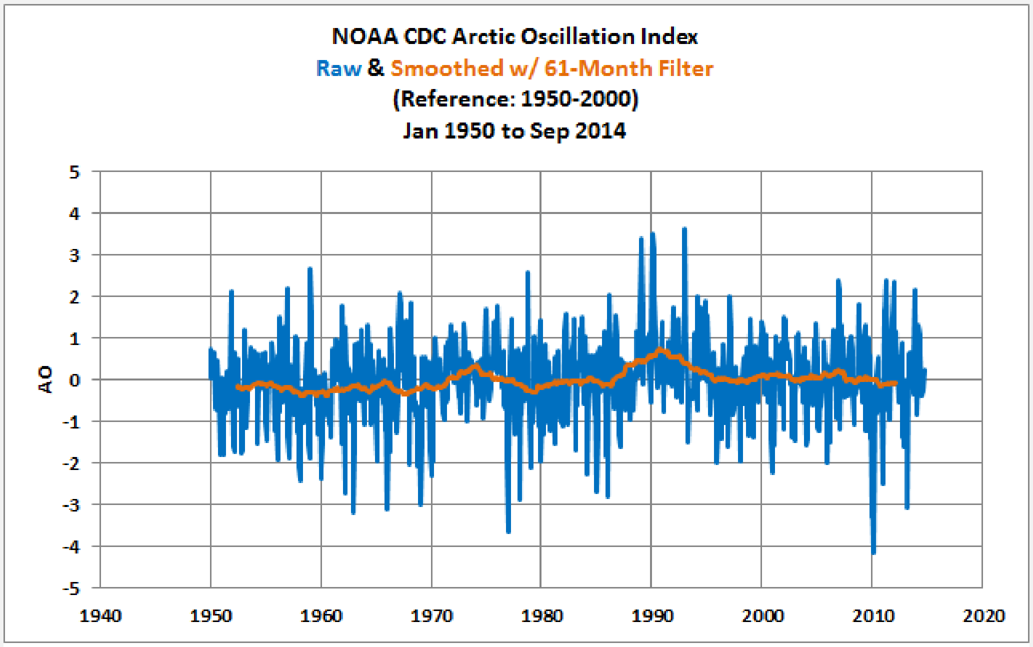


Figure 3.12-4

ARCTIC OSCILLATION AND SEA ICE

The Arctic Oscillation is important to meteorologists for weather forecasts, especially in boreal winter. However, the Arctic Oscillation—and the related wind patterns in the Arctic—also have strong impacts on seasonal Arctic sea ice losses.

We have to keep in mind that Arctic sea ice is floating on the surface of the Arctic Ocean. While most of the Arctic Ocean is surrounded by continental land masses, it is open to the Pacific through the Bering Strait and basically wide open to the North Atlantic.

If wind patterns forced the older and thicker sea ice toward the center of the Arctic Ocean, there would be less seasonal sea ice loss. On the other hand, if wind patterns helped to push the older, thicker sea ice out of the Arctic Ocean into the warmer North Atlantic that would help to enhance sea ice loss in the Arctic that season. See the article The Arctic Oscillation, winter storms, and sea ice posted at the National Snow and Ice Data Center (NSIDC) website. The person being quoted is Research Scientist Walt Meier. The article reads under the heading of "AO and sea ice":

> *The impacts of AO on North American weather can affect our daily lives, but climate scientists want to know how the AO influences sea ice conditions in the Arctic Ocean. While over the long term, sea ice extent has been declining, during any particular winter extent can vary due to weather conditions. Meier said, "The Arctic Oscillation primarily affects sea ice through winds that cause changes in where the sea ice drifts." When the Arctic Oscillation is in its negative mode, he*

> *said, the winds and ice tend to flow in a clockwise direction, generally keeping more of the older, thicker ice in the middle of the Arctic. In the positive phase, that old ice tends to get pushed out of the Arctic along the Greenland coast. Meier said, "This means that the sea ice tends to be younger and thinner and more prone to melt after a winter with a strong positive Arctic Oscillation." The AO is just one of many weather wildcards that could spell the difference between a low sea ice year and a record low year. See the Icelights article, Climate Change or Variability: What Rules Sea Ice?*

NO SURPRISE: CLIMATE MODELS DO A POOR JOB OF SIMULATING THE ARCTIC OSCILLATION

According to Zou, et al. (2013) Representation of the Arctic Oscillation in the CMIP5 Models, simulations of the Arctic Oscillation are flawed in the climate models used by the IPCC for their 5th Assessment Report. The abstract reads:

> *The temporal variability and spatial pattern of the Arctic Oscillation (AO) simulated in the historical experiment of 26 coupled climate models participating in the Coupled Model Intercomparison Project Phase 5 (CMIP5) are evaluated. Spectral analysis of the monthly AO index indicates that 23 out of the 26 CMIP5 models exhibit no statistically significant spectral peak in the historical experiment, as seen in the observations. These models are able to reproduce the AO pattern in the sea level pressure anomaly field during boreal winter, but the intensity of the AO pattern tends to be overestimated in all the models. The zonal-mean zonal wind anomalies associated with the AO is dominated by a meridional dipole in the mid-high latitudes of the Northern Hemisphere during boreal winter, which is well reproduced by only a few models. Most models show significant biases in both strength and location of the dipole compared to the observation. In considering the temporal variability as well as spatial structures in both horizontal and vertical directions, the MPI-ESM-P model reproduces an AO pattern that resembles the observation the best.*

SUMMARY

The Arctic Oscillation is a naturally occurring variation in the atmospheric pressure of the Northern Hemisphere. It corresponds to known weather and wind patterns there. Wind patterns associated with the Arctic Oscillation can also have strong impacts on seasonal sea ice losses in the Arctic Ocean.

3.13 – Atmospheric Mode – Southern Annular Mode, a.k.a. Antarctic Oscillation (AAO)

The Southern Annular Mode or Antarctic Oscillation (AAO) is similar to the Arctic Oscillation, inasmuch as it's determined the same way, but, obviously, it occurs in the Southern Hemisphere.

OVERVIEW

Australia's Bureau of Meteorology has an excellent and easy-to-understand introduction to the Southern Annular Mode.

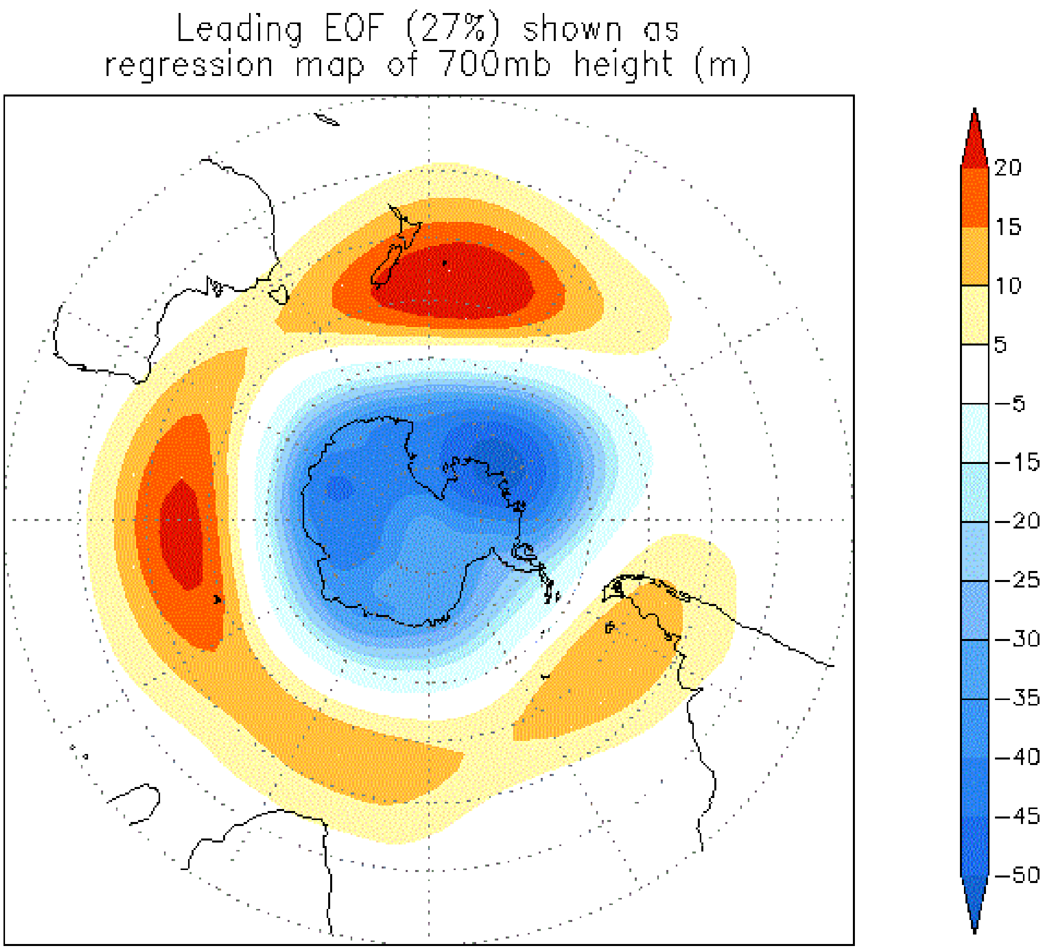
> *The Southern Annular Mode (SAM), also known as the Antarctic Oscillation (AAO), describes the north–south movement of the westerly wind belt that circles Antarctica, dominating the middle to higher latitudes of the southern hemisphere.*
>
> *The changing position of the westerly wind belt influences the strength and position of cold fronts and mid-latitude storm systems, and is an important driver of rainfall variability in southern Australia.*
>
> *In a positive SAM event, the belt of strong westerly winds contracts towards Antarctica. This results in weaker than normal westerly winds and higher pressures over southern Australia, restricting the penetration of cold fronts inland.*
>
> *Conversely, a negative SAM event reflects an expansion of the belt of strong westerly winds towards the equator. This shift in the westerly winds results in more (or stronger) storms and low pressure systems over southern Australia. During autumn and winter, a positive SAM value can mean cold fronts and storms are farther south, and hence southern Australia generally misses out on rainfall. However, in spring and summer, a strong positive SAM can mean that southern Australia is influenced by the northern half of high pressure systems, and hence there are more easterly winds bringing moist air from the Tasman Sea. This increased moisture can turn to rain as the winds hit the coast and the Great Dividing Range.*
>
> *In recent years, a high positive SAM has dominated during autumn–winter, and has been a significant contributor to the 'big dry' observed in southern Australia from 1997 to 2010.*

THE ANTARCTIC OSCILLATION (AAO) INDEX

The Antarctic Oscillation (AAO) Index is determined the same way as the Arctic Oscillation Index. Researchers first determined the dominant spatial pattern of atmospheric pressures in the mid-to-high latitudes (90S-20S) of the Southern Hemisphere. See Figure 3.13-1. Using that statistical analysis, they then compare the spatial pattern for a specific time to that dominant spatial pattern. The closer the match, the higher the Antarctic Oscillation Index value. If the spatial pattern were to be reversed, with low atmospheric pressures where highs normally exist and with high atmospheric pressures where lows normally exist, the Antarctic Oscillation Index values would be negative.

NOAA CPC

Antarctic Oscillation "Loading Pattern"



Source:
http://www.cpc.ncep.noaa.gov/products/precip/CWlink/daily_ao_index/aao/aao.loading.shtml

Figure 3.13-1

Figure 3.13-1 presents what the NOAA Climate Prediction Center (CPC) calls the Antarctic Oscillation "Loading Pattern". Their description reads:

> *The loading pattern of the AAO is defined as the leading mode of Empirical Orthogonal Function (EOF) analysis of monthly mean 700 hPa height during 1979-2000 period.*

Further explanations of how the Antarctic Oscillation Index (AAO) is calculated can be found on the following NOAA CPC Teleconnections Pattern Calculation Procedure webpage. It's the same discussion for the Arctic Oscillation Index. The NOAA reference for the Antarctic Oscillation Index is the 2000 paper by Mo, K. C., Relationships between Low-Frequency Variability in the Southern Hemisphere and Sea Surface Temperature Anomalies.

ANTARCTIC OSCILLATION INDEX DATA

The Antarctic Oscillation (AAO) Index data are available from the NOAA CPC Antarctic Oscillation (AAO) webpage, specifically here in ascii format. Figure 3.13-2 presents the Antarctic Oscillation Index data in "raw" form and smoothed with a 61-month running-mean filter.

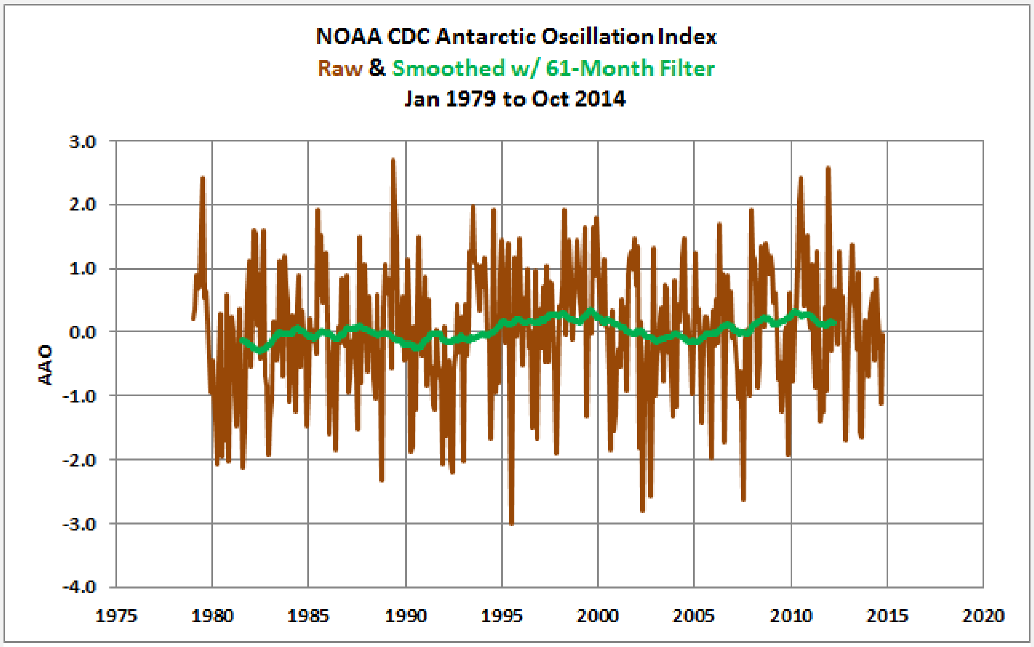


Figure 3.13-2

Figure 3.13-3 presents the smoothed version of the Antarctic Oscillation Index data. It shows decadal variability. Because we only have a few decades of data, it is difficult to tell if those are decadal variations on a positive trend or, simply, an upward shift in the 1990s.

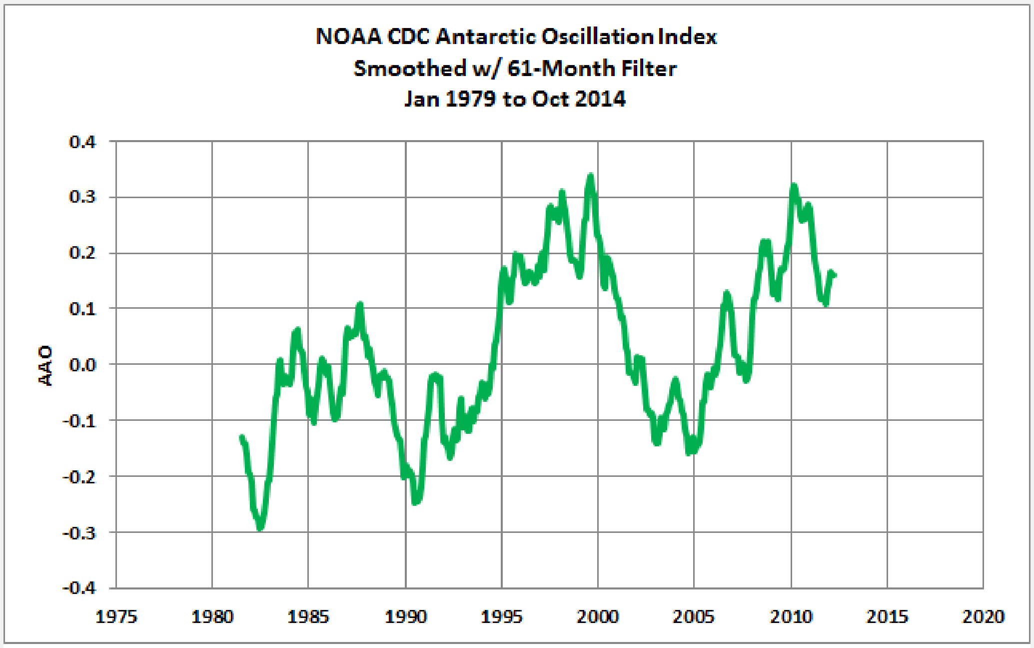


Figure 3.13-3

ANTARCTIC OSCILLATION AND SEA ICE IN THE SOUTHERN HEMISPHERE

The Antarctic Oscillation—which "describes the north–south movement of the westerly wind belt that circles Antarctica"—will impact where the sea ice gathers that surrounds Antarctica. The NASA Earth Observatory website has an introductory discussion of the natural factors that have strong influences on sea ice that surrounds Antarctica. See their Antarctic sea ice feature. With respect to the Antarctic Oscillation, they write:

> *Similar to the Arctic, the Antarctic experiences atmospheric oscillations and recurring weather patterns that influence sea ice extent. The primary variation in atmospheric circulation in the Antarctic is the Antarctic Oscillation, also called the Southern Annular Mode. Like the Arctic Oscillation, the Antarctic Oscillation involves a large-scale seesawing of atmospheric mass between the pole and the mid-latitudes. This oscillation can intensify, weaken, or shift the location of semi-permanent low- and high-pressure weather systems. These changes influence wind speeds, temperature, and the track that storms follow, any of which may influence sea ice extent.*
>
> *For example, during positive phases of the Antarctic Oscillation, the prevailing westerly winds that circle Antarctica strengthen and move southward. The change in winds can change the way ice is distributed among the various sectors. In addition, the strengthening of the westerlies isolates much of the*

> *continent and tends to have an overall cooling effect, but it causes dramatic warming on the Antarctic Peninsula, as warmer air from over the oceans to the north is drawn southward. The winds may drive the ice away from the coast in some areas and toward the coast in others. Thus, the same climate influence may lessen sea ice in some sectors and increase it in others.*

SUMMARY

The Antarctic Oscillation is a naturally occurring variation in the atmospheric pressures and associated wind patterns in the Southern Hemisphere. It is also known as the Southern Annular Mode. It has a strong influence on weather in the Southern Hemisphere and on where seasonal sea ice accumulates in the Southern Ocean surrounding Antarctica.

3.14 – Teleconnections

Because it sounds so odd, the weather- and climate-related term "teleconnection" can create a lot of skepticism. Teleconnection seems like it would be more appropriate as an electronic communications term.

Teleconnections do exist in weather and climate patterns. The term teleconnection is used to express a known interrelationship between weather conditions in distant parts of the globe. The American Meteorological Society defines teleconnection as:

1. *A linkage between weather changes occurring in widely separated regions of the globe.*
2. *A significant positive or negative correlation in the fluctuations of a field at widely separated points.*

Most commonly applied to variability on monthly and longer timescales, the name refers to the fact that such correlations suggest that information is propagating between the distant points through the atmosphere.

The glossary at NOAA's National Weather Service website presents a simpler definition of teleconnection:

Linkage between changes in atmospheric circulation occurring in widely separated parts of the globe.

The components of the Southern Oscillation Index are often used as a well-known example of a teleconnection. That is, when the sea level pressure in Tahiti rises, the sea level pressure in Darwin, Australia typically falls, and vice versa.

Another example of a teleconnection that I've used in the past is the interrelationship between an El Niño taking place in the tropical Pacific and the response (warming) of the sea surfaces of the tropical North Atlantic. Typically, the sea surfaces of the tropical North Atlantic will warm about 3 months after the equatorial Pacific warms during an El Niño…even though Central America separates the two bodies of water.

Wang (2005) **ENSO, Atlantic Climate Variability, And The Walker And Hadley Circulation** provides a detailed discussion of how those changes occur. In layman terms, those two oceans might be separated by the land mass of Central America, but the atmosphere above them is not. We already know how and why the trade winds weaken in the eastern tropical Pacific during an El Niño. (Refer back to the discussion in Chapter 3.7 – Ocean Mode: El Niño and La Niña, under the heading of IMPACTS OF EL NIÑO AND LA NIÑA ON THE ATMOSPHERE.) Those changes in atmospheric circulation in the Pacific, in turn, cause the trade winds in the tropical North Atlantic to weaken, too. The slower trade winds blowing across the surface of the tropical North Atlantic Ocean don't cool the surface waters as much as they normally would; there's less evaporation with the slower trade winds; so the sea surface temperatures warm in the tropical North Atlantic. That's only part of the explanation. With trade winds in the North Atlantic at their normal strength, cool waters from below the surface are pulled up to the surface there. In other words, where upwelling occurs, it is occurring at its normal rates when the trade winds are at their normal strengths. When the North Atlantic trade winds weaken during an El Niño, there is less cool water being pulled up to the surface, so the tropical North Atlantic warms as a result of that weakening process also.

There are known teleconnections associated with the atmospheric and oceanic indices we've already discussed. For examples, see:

- The NOAA CPC North Atlantic Oscillation (NAO) webpage
- Robert Stewart's El Niño teleconnections webpage at the Texas A&M OceanWorld website.

There is a wealth of information online about the typical impacts of ENSO on precipitation and temperature around the globe. They would be considered teleconnections when remote to the tropical Pacific. Examples:

- NOAA Climate Prediction Center (CPC) website titled The ENSO Cycle.
- NOAA/NWS webpage Weather Impacts of ENSO.
- Royal Netherlands Meteorological Institute (KNMI) website Effects of El Niño on world weather
- NOAA Earth Systems Research Laboratory (ESRL) has a webpage with links to ENSO's effect on climate by month.

DO CLIMATE MODELS PROPERLY SIMULATE TELECONNECTIONS?

No. Climate models do not simulate teleconnections properly. For confirmation we can turn to the 2012 paper Systematic Comparison of ENSO Teleconnection Patterns between Models and Observations by Yang and DelSole. The abstract includes (my boldface):

> *Statistically significant ENSO-teleconnection patterns are detected in both observations and models, and in all continents and in both winter and summer seasons, except in two cases: (1) Europe (both seasons and variables), and (2) North American (both variables in boreal summer).* ***Despite many ENSO-teleconnection patterns being significant, however, the patterns do not necessarily agree between observations and models****.*

In other words, while climate models can create teleconnections relating to El Niño and La Niña events, they bear no relationship to the El Niño- and La Niña-related teleconnections as they exist in nature for most of the globe.

3.15 – Atmospheric Mode – Miscellaneous

There are a number of other atmospheric modes of variability that can be found in discussions of climate. Some of these modes are referred to often in scientific papers, others very rarely. This chapter provides a simple overview of many of them.

NORTHERN HEMISPHERE

There are numerous other weather-related climate indices that NOAA monitors and updates for the Northern Hemisphere. See their Teleconnection Introduction webpage. NOAA also updates the following indices. Links are to the description pages, where the quotes are taken from:

North Atlantic Oscillation (NAO)

> *…results in changes in temperature and precipitation patterns often extending from eastern North America to western and central Europe.*

East Atlantic Pattern (EA)

> *The positive phase of the EA pattern is associated with above-average surface temperatures in Europe in all months, and with below-average temperatures over the southern U.S. during January-May and in the north-central U.S. during July-October. It is also associated with above-average precipitation over northern Europe and Scandinavia, and with below-average precipitation across southern Europe.*

East Atlantic/West Russia Pattern (EA/WR)

> *The main surface temperature anomalies associated with the positive phase of the EATL/ WRUS pattern reflect above-average temperatures over eastern Asia, and below-average temperatures over large portions of western Russia and northeastern Africa. The main precipitation departures reflect generally above-average precipitation in eastern China and below-average precipitation across central Europe.*

Scandinavia Pattern (SCA)

> *The positive phase of the Scandinavia pattern is associated with below-average temperatures across central Russia and also over western Europe. It is also associated with above-average precipitation across central and southern Europe, and below-average precipitation across Scandinavia.*

Polar/ Eurasia Pattern (POL)

> *The Polar/Eurasian pattern is mainly associated with above-average temperatures in eastern Siberia and below-average temperatures in eastern China. It is also associated with above-average precipitation in the polar region north of Scandinavia.*

West Pacific Pattern (WP)

> *The positive phase of the WP pattern is associated with above-average temperatures over the lower latitudes of the western North Pacific in both winter and spring, and with below-average temperatures over eastern Siberia in all seasons. It is also associated with above-average precipitation in all seasons over the high latitudes of the North Pacific, and below-average precipitation across the central North Pacific especially during the winter and spring.*

EastPacific/ North Pacific Pattern (EP/NP)

> *The positive phase of the EP-NP pattern is associated with above-average surface temperatures over the eastern North Pacific, and below-average temperatures over the central North Pacific and eastern North America. The main precipitation anomalies associated with this pattern reflect above-average precipitation in the area north of Hawaii and below-average precipitation over southwestern Canada.*

Pacific/ North American Pattern (PNA)

> *The positive phase of the PNA pattern is associated with above-average temperatures over western Canada and the extreme western United States, and below-average temperatures across the south-central and southeastern U.S. The PNA tends to have little impact on surface temperature variability over North America during summer. The associated precipitation anomalies include above-average totals in the Gulf of Alaska extending into the Pacific Northwestern United States, and below-average totals over the upper Midwestern United States.*

Tropical/ Northern Hemisphere Pattern (TNH)

> *The positive phase of the TNH pattern is associated with below-average surface temperatures throughout the western and central United States, and across central and eastern Canada. It is also associated with above-average precipitation across the central and eastern subtropical North Pacific, and below-average precipitation in the western United States and across Cuba, the Bahama Islands, and much of the central North Atlantic Ocean.*

Pacific Transition Pattern (PT)

> *The PT pattern is associated with above-average surface temperatures in the western subtropical North Pacific, the subtropical North Atlantic, and throughout western North America, and with below-average temperatures over the eastern half of the United States. The main precipitation departures associated with the PT pattern include above-average precipitation in the southeastern U.S., and below-average precipitation near Hawaii and across the northern tier of the United States.*

GRAPHS OF NORTHERN HEMISPHERE TELECONNECTION INDICES

There are links to additional discussions about the methods used by NOAA to determine the indices discussed above on their Northern Hemisphere Teleconnection Patterns webpage. Also included on the webpage is a link to data. See the Historical Archive of all Indices link.

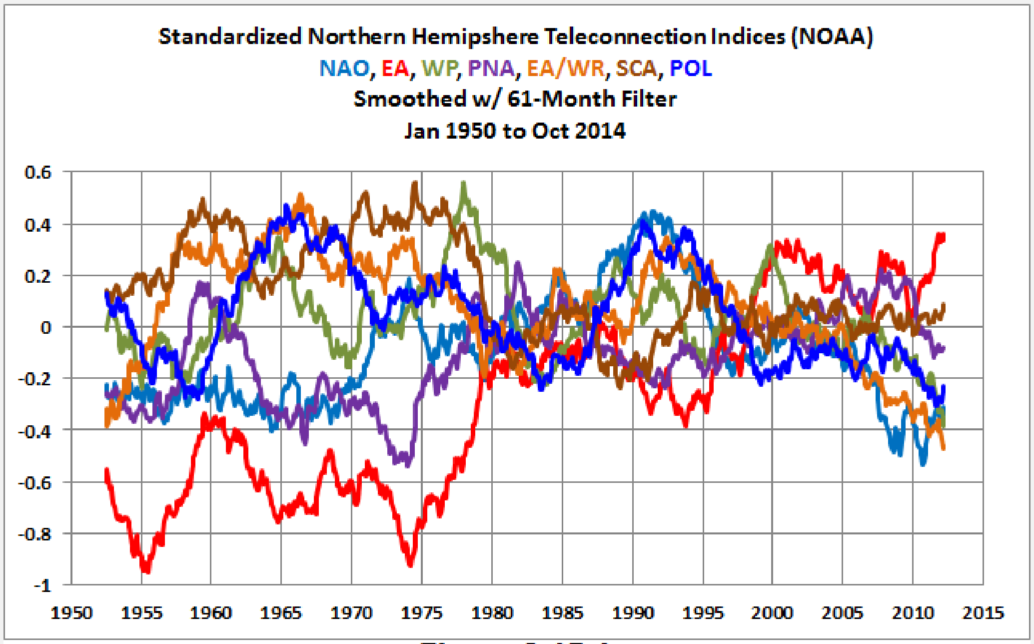


Figure 3.15-1

It's likely that you'll never see some of these indices discussed in any climate-related papers, but I figured it would be best to plot them all as a reference…just in case they make it into some papers in the future.

I've excluded the following indices from the presentations of smoothed (61-month) monthly data.

- The Tropical/ Northern Hemisphere Pattern (TNH) index only includes data for the boreal winter months of December to February,

- The East Pacific/ North Pacific Pattern (EP/NP) index excludes December data, and
- The Pacific Transition Pattern (PT) index only covers the months of August and September.

Figure 3.15-1, above, is a spaghetti graph of the 7 remaining Northern Hemisphere teleconnection pattern indices. If you look closely, you'll note that two of them appear to mimic one another. They are the East Atlantic/West Russia Pattern (EA/WR) index and the Polar/Eurasia Pattern (POL). I've isolated them in Figure 3.15-2. While the two indices tend to more-or-less agree with one another on decadal timespans, they correlate very poorly with one another on a monthly basis, with a correlation coefficient of -0.01). That's about as bad as you can get.

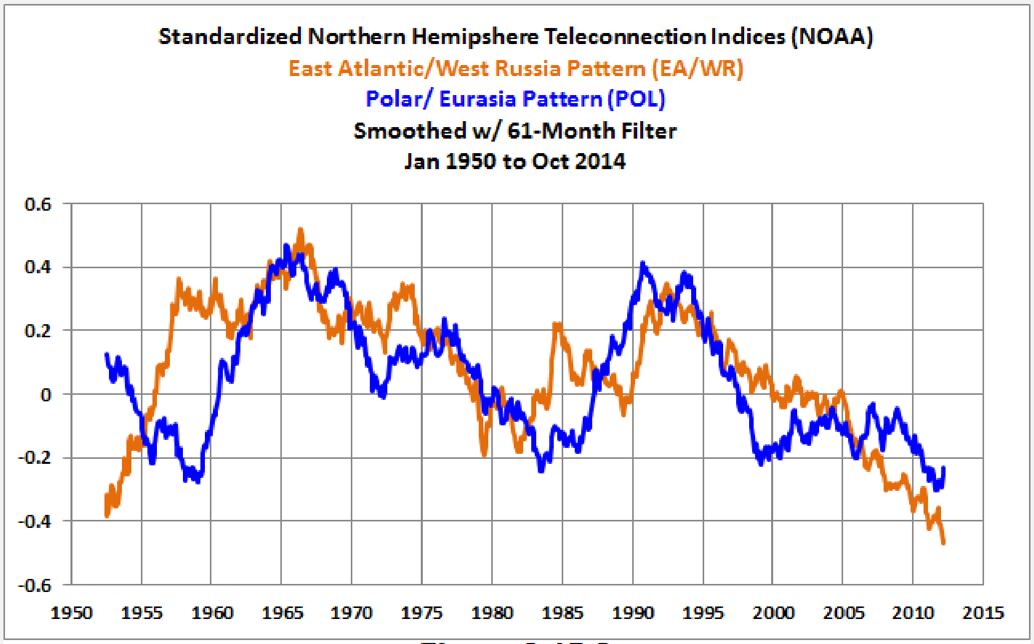


Figure 3.15-2

Next, the North Atlantic Oscillation (NAO) index is often used during discussions of the multidecadal variations in the sea surface temperatures (the Atlantic Multidecadal Oscillation or AMO) and meridional overturning circulation in the North Atlantic (AMOC). See Figure 3.15-3.

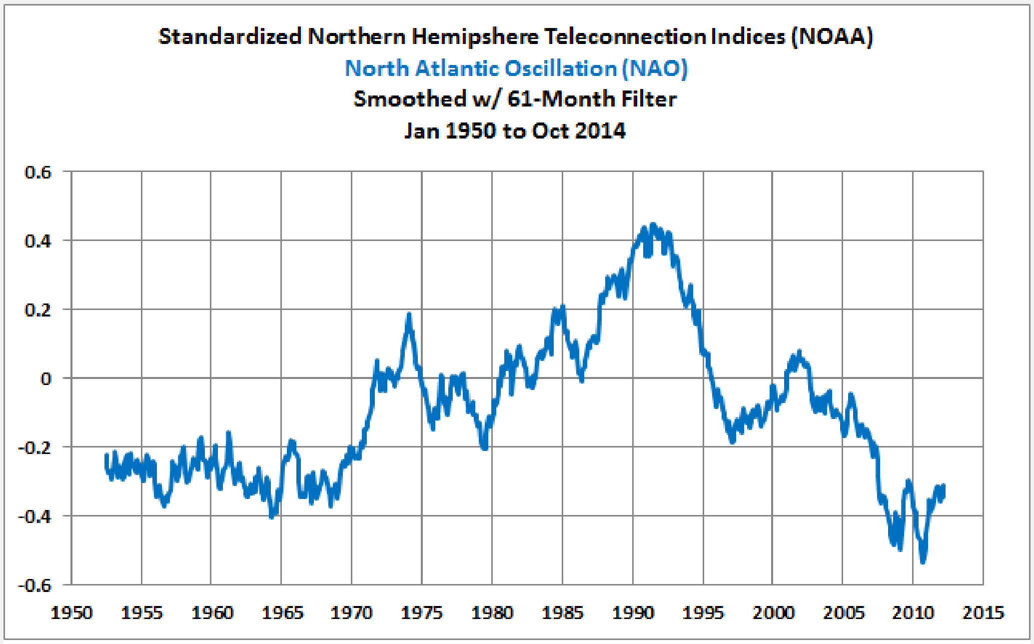


Figure 3.15-3

Of the 7 indices with monthly data, the East Atlantic Pattern (EA) index has the most significant increasing long-term trend, Figure 3.15-4.

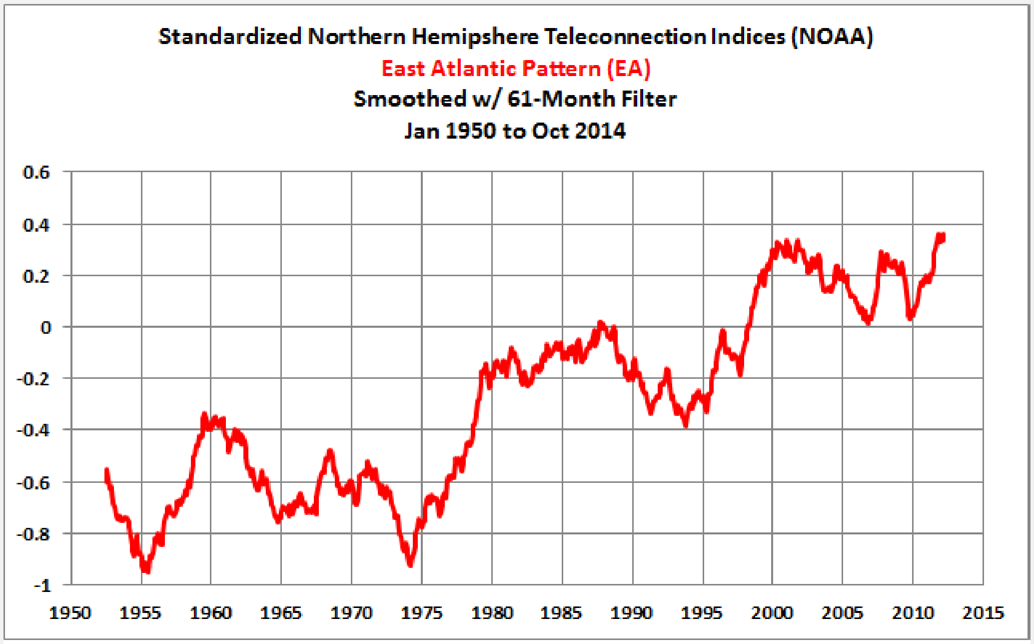


Figure 3.15-4

The Scandinavia Pattern (SCA) index is next. In Figure 3.15-5 below, note the very obvious climate shift in the late 1970s in the Scandinavia Pattern (SCA) index.

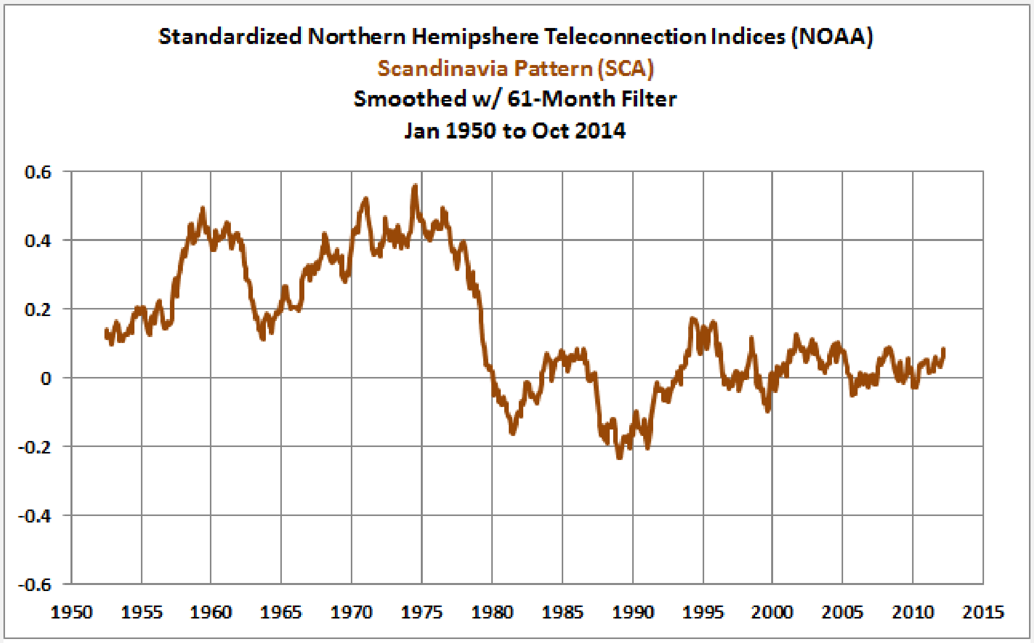


Figure 3.15-5

Next to last: After some early decadal volatility, the Pacific/North American Pattern (PNA) index, Figure 3.15-6, showed a moderate long-term positive trend until the recent drop-off in 2010.

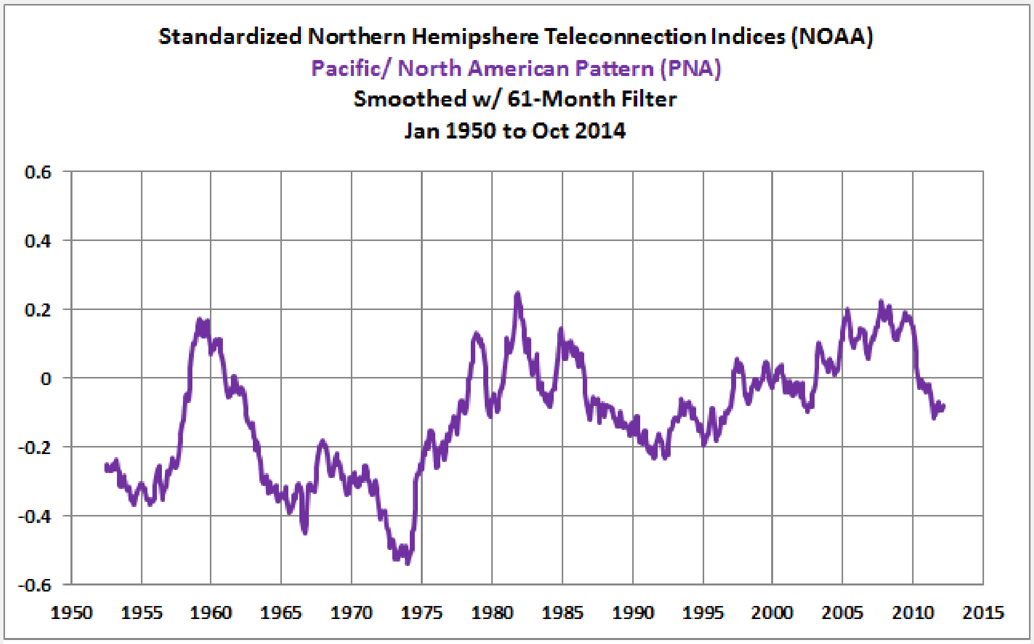


Figure 3.15-6

The last of the NOAA Northern Hemisphere Teleconnection indices, the West Pacific Pattern (WP) index, Figure 3.15-7, showed some early strong decadal variations. The variability lessened from the 1980s to about 2005, when there was a steady decline in the index.

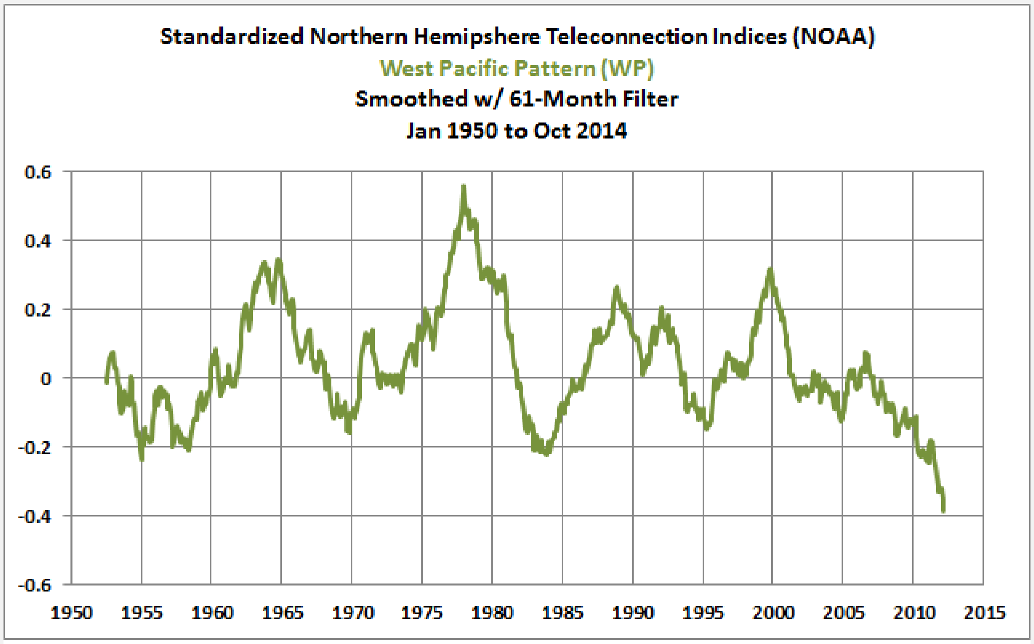


Figure 3.15-7

WE CAN'T OVERLOOK THE MADDEN-JULIAN OSCILLATION (MJO)

From time to time, you may hear your local meteorologist refer to the Madden-Julian Oscillation or MJO. The University of Wyoming webpage about The Madden-Julian Oscillation, by Geerts and Wheeler, provides a relatively simple description:

> The MJO, also referred to as the 30-60 day or 40-50 day oscillation, turns out to be the main intra-annual fluctuation that explains weather variations in the tropics. The MJO affects the entire tropical troposphere but is most evident in the Indian and western Pacific Oceans. The MJO involves variations in wind, sea surface temperature (SST), cloudiness, and rainfall.

The Madden-Julian Oscillation directly impacts seasonal weather in the tropics, but because the weather outside of the tropics is in part a function of the tropical weather, the Madden-Julian Oscillation also has noticeable impacts globally.

If you're interested in a very good, relatively simple introduction to the Madden-Julian Oscillation, see the post What is the MJO, and why do we care? at the NOAA ENSO blog.

CLOSING CHAPTER COMMENT

Before you spend too much time trying to determine any relationships between the indices discussed in this chapter and regional weather, consider two things:

First, the relationships between the indices and regional weather are tendencies. That is, when a specific index is in the positive mode, the weather patterns presented by NOAA tend to exist. They don't always exist; they tend to.

Second, there are other factors that also have known influences on regional temperature and precipitation—such as El Niño and La Niña events, the Atlantic Multidecadal Oscillation and the Pacific Decadal Oscillation.

3.16 – Ocean Mode – Indian Ocean Dipole

Australia's Bureau of Meteorology (BOM) includes a discussion of the Indian Ocean Dipole (IOD) in its ENSO Wrap-Up webpages, because the Indian Ocean Dipole can impact the effects of ENSO events on Australia. The BOM also has an introductory discussion of the Indian Ocean Dipole on a separate About the Indian Ocean Dipole webpage. There they write in the first paragraph:

> The Indian Ocean Dipole (IOD) is a coupled ocean and atmosphere phenomenon in the equatorial Indian Ocean that affects the climate of Australia and other countries that surround the Indian Ocean basin (Saji et al. 1999).

The following is the abstract of Saji et al (1999), A dipole mode in the tropical Indian Ocean (my boldface).

> *For the tropical Pacific and Atlantic oceans, internal modes of variability that lead to climatic oscillations have been recognized, but in the Indian Ocean region a similar ocean–atmosphere interaction causing interannual climate variability has not yet been found. Here we report an analysis of observational data over the past 40 years, showing a dipole mode in the Indian Ocean: a pattern of internal variability with anomalously low sea surface temperatures off Sumatra and high sea surface temperatures in the western Indian Ocean, with accompanying wind and precipitation anomalies. The spatio-temporal links between sea surface temperatures and winds reveal a strong coupling through the precipitation field and ocean dynamics. This air–sea interaction process is unique and inherent in the Indian Ocean, and is* ***shown to be independent of the El Niño/Southern Oscillation****. The discovery of this dipole mode that accounts for about 12% of the sea surface temperature variability in the Indian Ocean—and,* ***in its active years, also causes severe rainfall in eastern Africa and droughts in Indonesia—brightens the prospects for a long-term forecast of rainfall anomalies in the affected countries.***

The Indian Ocean Dipole is also strongly tied to India's summer monsoon rainfall. This is discussed in Ashok et al. (2001) Impact of the Indian Ocean Dipole on the Relationship between the Indian Monsoon Rainfall and ENSO. (Preprint copy is here.) The Ashok et al. abstract reads:

> *The influence of the recently discovered Indian Ocean Dipole (IOD) on the interannual variability of the Indian summer monsoon rainfall (ISMR) has been investigated for the period 1958-1997. The IOD and the El Niño/Southern*

> *Oscillation (ENSO) have complementarily affected the ISMR during the last four decades. Whenever the ENSO-ISMR correlation is low (high), the IOD-ISMR correlation is high (low). The IOD plays an important role as a modulator of the Indian monsoon rainfall, and influences the correlation between the ISMR and ENSO. We have discovered that the ENSO-induced anomalous circulation over the Indian region is either countered or supported by the IOD-induced anomalous meridional circulation cell, depending upon the phase and amplitude of the two major tropical phenomena in the Indo-Pacific sector.*

The Indian Ocean Dipole is normally presented using a dataset called the Dipole Mode Index (DMI). The Dipole Mode Index is calculated as the sea surface temperature anomaly <u>difference</u> between western (10S-10N, 50E-70E) and eastern (10S-0, 90E-110E) portions of the tropical Indian Ocean, with the eastern data subtracted from the western. Refer to the map in Figure 3.16-1.

Indian Ocean Dipole - Dipole Mode Index (DMI)

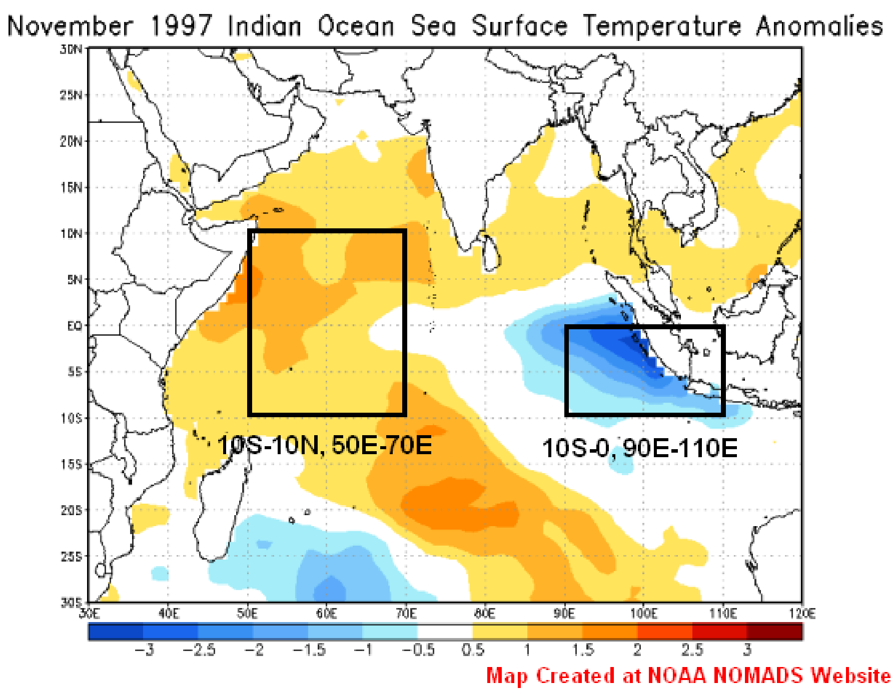


Figure 3.16-1

# # #

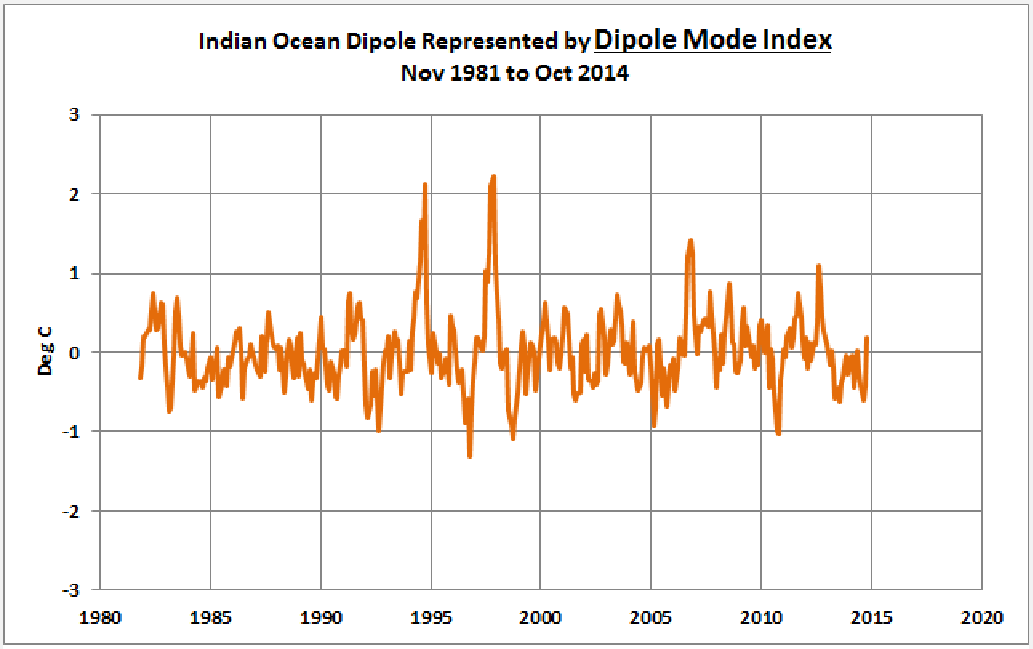


Figure 3.16-2

A time-series graph of the Dipole Mode Index is presented in Figure 3.16-2. There is a major spike in 1997/98 that appears related to the 1997/98 El Niño, but the other two major El Niño events in1982/83 and 1986/87/88 appear to have had little impact on the Dipole Mode Index. Then again, the Dipole Mode Index seems to have exaggerated responses to the moderate El Niño events of 1994/95 and 2006/07.

Let's confirm the timing of the major spikes in the Dipole Mode Index by comparing it to an ENSO index, Figure 3.16-3. You'll note that the NINO3.4 sea surface temperature anomalies have not been scaled in this graph. That does not mean, however, that the sea surface temperature anomalies in the regions that make up the Dipole Mode Index are varying as much as the NINO3.4 data. The NINO3.4 data are the "raw" sea surface temperature anomalies for the NINO3.4 region, while the Dipole Mode Index portrays the temperature difference between two regions. If the sea surface temperature anomalies in the eastern Dipole Mode Region are dropping when they're rising in the western region, the Dipole Mode Index would reflect the difference between the rise and fall. On the other hand, they would offset one another if they warmed and cooled in unison.

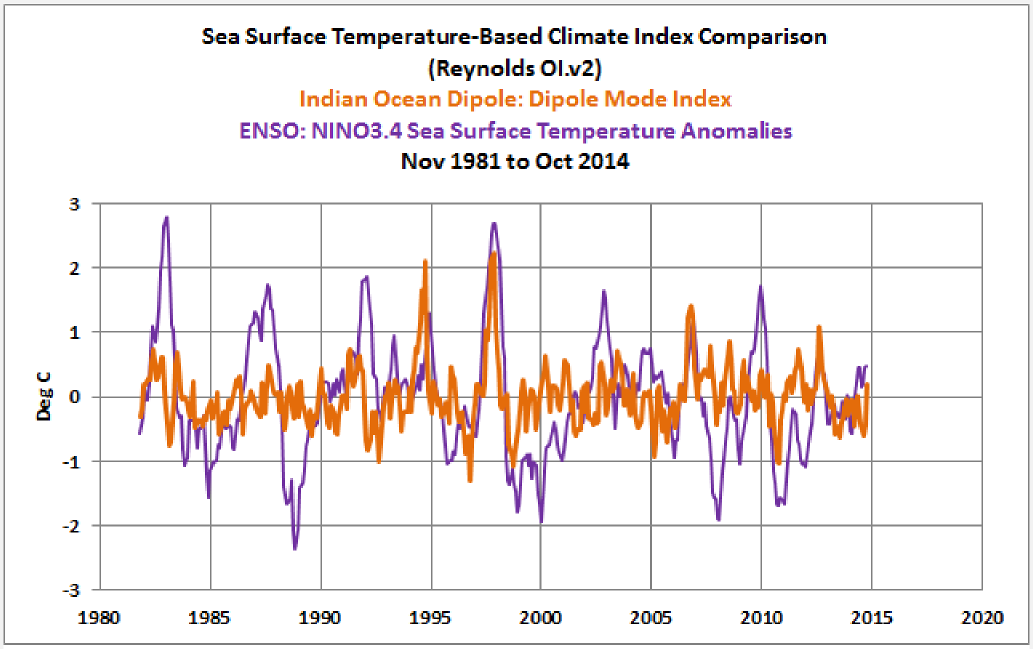


Figure 3.16-3

Note how the Dipole Mode Index responds to some El Niño and La Niña events, but not others.

Comparing the ENSO index to the sea surface temperature anomalies of the eastern and western regions of the Dipole Mode Index helps to illustrate the causes for the spikes, and they also present a few curiosities. Figure 3.16-4 (below) shows the sea surface temperature anomalies for the Western Region of the Dipole Mode Index compared to scaled (0.4) NINO3.4 sea surface temperature anomalies. I used the scaling to reduce the variations in the NINO3.4 data, or, in other words, the sea surface temperatures of the NINO3.4 region have much greater variations (2.5 times greater). Both datasets were smoothed with 12-month running-average filters.

That region represents a good portion of the western tropical Indian Ocean. The western Dipole region appears to respond proportionately to most El Niño events, with a few exceptions. The response to the 1991/92 El Niño appears to have been suppressed by the 1991 eruption of Mount Pinatubo, just as the response to the 1982/83 El Niño was impacted by the 1982 eruption of El Chichon. Notice also how the sea surface temperature anomalies of the western Dipole Mode Index Region fail to cool fully in response to the1988/89 and 1998/99/00/01 La Niña events, but they cool in response to other La Niñas. The 1988/89 and 1998/99/00/01 La Niña events followed the two strongest El Niño events that weren’t countered by volcanic eruptions.

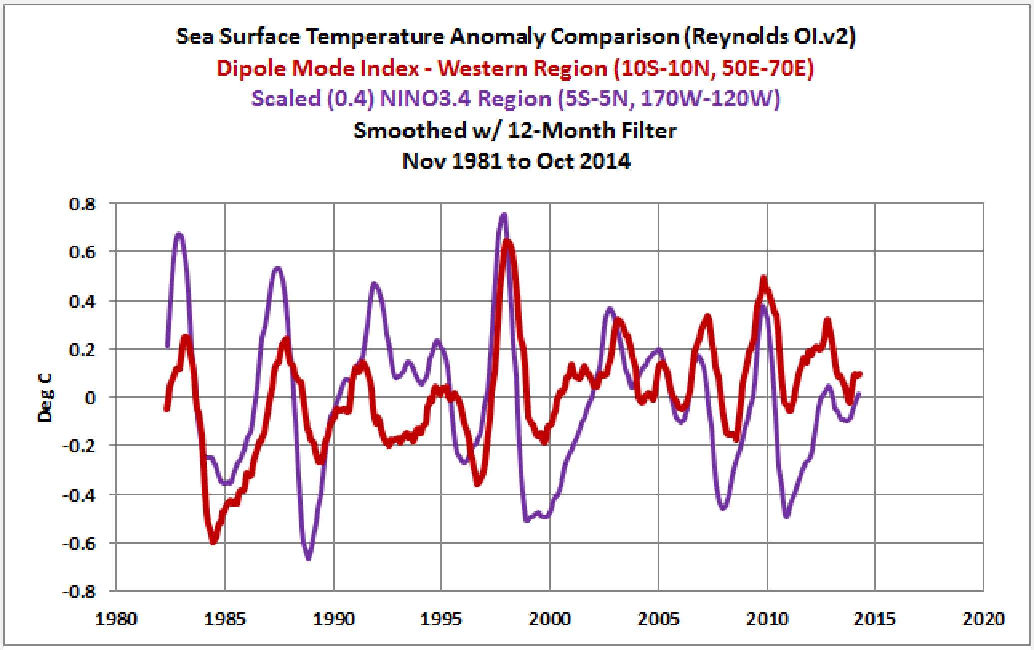


Figure 3.16-4

This is one of the examples of how sea surface temperatures (in areas remote to the eastern equatorial Pacific) respond in an unusual way to major El Niño events; they don't react to the trailing La Niña. We've discussed the reasons for that in Chapter 3.7 – Ocean Mode: El Niño and La Niña. However, that wouldn't explain the strong spikes in the Dipole Mode Index during the 1994/95, 1997/98 and 2006/07 El Niño events as shown in Figure 3.16-3 above.

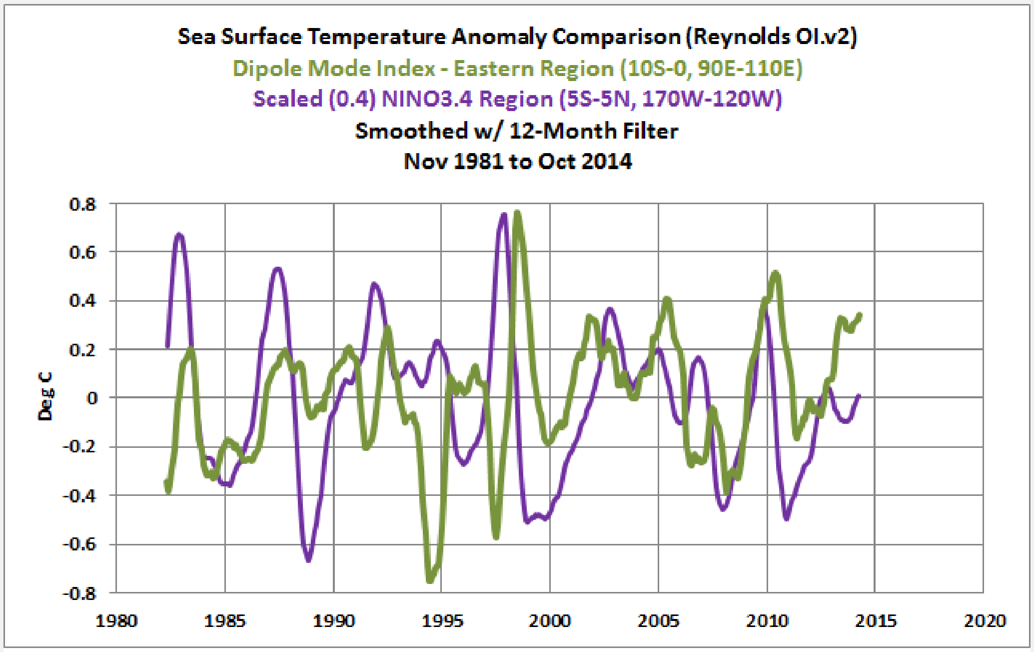


Figure 3.16-5

There has to be something unusual about how the sea surface temperature anomalies of the eastern Dipole Mode Index region respond to ENSO events. Referring to the comparison graph in Figure 3.16-5, there is unusual behavior. The eastern Dipole region data can run in and out of synch with the ENSO index. Let's discuss what appears unusual. The sea surface temperature anomalies of the eastern dipole region do not cool during the 1988/89 La Niña. They cool a disproportionately large amount in advance of the 1994/95 El Niño. The eastern Dipole region anomalies cool initially in response to the 1997/98 El Niño but then turn around and warm with about a 6-month lag. Once again, they do not cool fully in response to the La Niña event of 1998/99/00/01, but warm in response to the rebound in the ENSO index as that La Niña event comes to an end. Then, there's the last bit of unusual behavior: the failure of the sea surface temperature anomalies of the eastern Dipole region to respond to the 2006/07 El Niño. The "proper" responses to the 2004/05 and 2009/10 El Niño events almost appear unusual, because everything else is so odd.

CLIMATE MODELS DO A POOR JOB OF SIMULATING THE INDIAN OCEAN DIPOLE

Weller and Cai (2013) is titled Realism of the Indian Ocean Dipole in CMIP5 Models: The Implications for Climate Projections. The title gives the impression that the climate model simulations of the Indian Ocean Dipole are realistic. But their findings are just the opposite. Their abstract reads:

> *An assessment of how well climate models simulate the Indian Ocean dipole (IOD) is undertaken using 20 coupled models that have partaken in phase 5 of the Coupled Model Intercomparison Project (CMIP5). Compared with models in phase 3 (CMIP3), no substantial improvement is evident in the simulation of the IOD pattern and/or amplitude during austral spring [September–November (SON)]. The majority of models in CMIP5 generate a larger variance of sea surface temperature (SST) in the Sumatra–Java upwelling region and an IOD amplitude that is far greater than is observed. Although the relationship between precipitation and tropical Indian Ocean SSTs is well simulated, future projections of SON rainfall changes over IOD-influenced regions are intrinsically linked to the IOD amplitude and its rainfall teleconnection in the model present-day climate. The diversity of the simulated IOD amplitudes in models in CMIP5 (and CMIP3), which tend to be overly large, results in a wide range of future modeled SON rainfall trends over IOD-influenced regions. The results herein highlight the importance of realistically simulating the present-day IOD properties and suggest that caution should be exercised in interpreting climate projections in the IOD-affected regions.*

In other words, because the Indian Ocean Dipole is tied to India's monsoons, any claims of monsoons worsening due to human-induced global warming are unjustified, because climate models cannot properly simulate the Indian Ocean Dipole.

CHAPTER SUMMARY

The Indian Ocean Dipole is a coupled ocean-atmosphere phenomenon that makes its presence known in the sea surface temperature anomalies of the tropical Indian Ocean. The Dipole Mode Index is used to represent the Indian Ocean Dipole. It is determined by subtracting the sea surface temperatures of the eastern tropical Indian Ocean from those in the western portion of the tropical Indian Ocean.

The sea surface temperatures of the regions used in the Dipole Mode Index are not varying as much as those in the NINO3.4 region. Because the Dipole Mode Index represents a temperature anomaly difference, the major spikes in it are caused by the sea surface temperatures in the eastern region cooling while the western region sea surface temperature anomalies are warming.

The Indian Ocean Dipole has a strong influence on India's summer monsoon rainfalls and on weather patterns in Australia and other countries that border the Indian Ocean. Climate models do not properly simulate the Indian Ocean Dipole.

3.17 – The Stadium Wave

In your online climate change research, you'll likely come across a discussion of "the stadium wave". The stadium wave is a reference to the wave created by spectators momentarily standing in succession at a sporting event in a stadium. This creates the appearance of a wave traveling around the seating areas of the stadium. While the spectators do not change seats as part of the wave, it looks like they do.

The stadium wave in climate change discussions refers to the hypothesis proposed in the 2013 paper Role for Eurasian Arctic shelf sea ice in a secularly varying hemispheric climate signal during the 20th century by Wyatt and Curry.

Locations of Eurasian Arctic Self Used in Wyatt and Curry (2013)
Presented as Their Figure 1
(Areas Shaded in Grey)

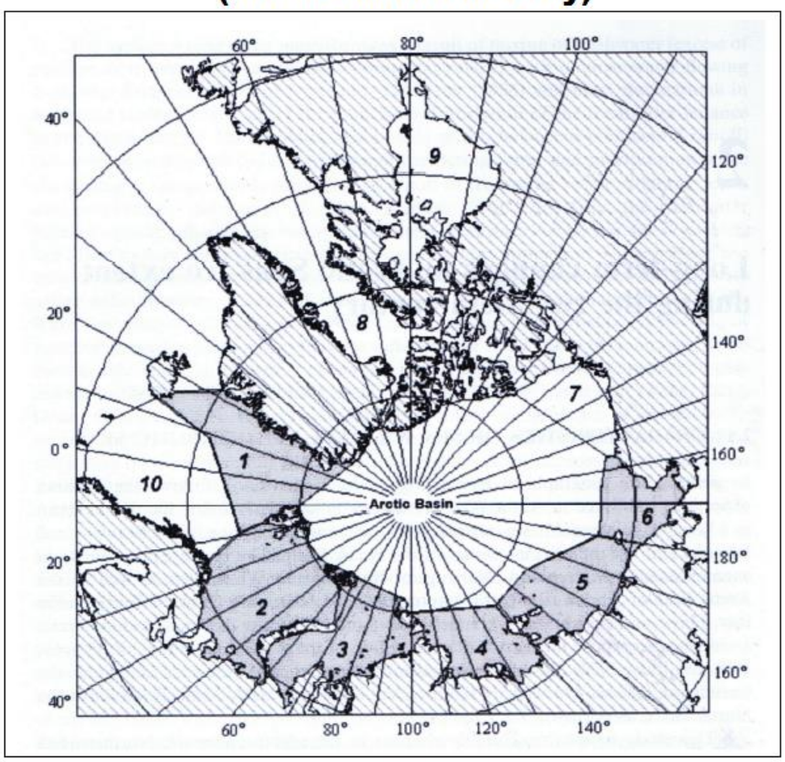


Fig. 1. Arctic Ocean and marginal seas used in this study (1-6 in this study (shaded in gray)): 1) Greenland Sea, 2) Barents Sea, 3) Kara Sea, 4) Laptev Sea, 5) East Siberian Sea, 6) Chukchi Sea. Categories of Seas include: NEB = 1&2; ArcSib = 3-6; WIE = 1-3; EIE = 4-6; and TIE = 1-6. [Also shown: 7) Beaufort Seas, 8) Baffin Bay, 9) Hudson Bay, and 10) the Norwegian Sea.] Adapted with permission from: Frolov et al. 2009.

Figure 3.17-1

One of the many excuses climate modelers use for not including known coupled ocean-atmosphere processes in their simulations of Earth's climate is that those processes are chaotic. Wyatt and Curry (2013) suggest that variations in those processes are not as random as once thought, that there are a group of coupled ocean, sea ice and atmosphere interactions that occur roughly in sequence to cause multidecadal variations in the surface temperatures of the Northern Hemisphere. The two primary signals, according to Wyatt and Curry (2013), are (1) the multidecadal variations in the sea surface temperatures of the North Atlantic, known as the Atlantic Multidecadal Oscillation (which we discussed in Chapter 3.3 – Ocean Mode: Atlantic Multidecadal Oscillation) and (2) the multidecadal variations in the sea ice extent in the seas of the Eurasian Arctic shelf. See Figure 3.17-1 above for those sea ice regions.

The abstract of Wyatt and Curry (2013) reads:

> *A hypothesized low-frequency climate signal propagating across the Northern Hemisphere through a network of synchronized climate indices was identified in previous analyses of instrumental and proxy data. The tempo of signal propagation is rationalized in terms of the multidecadal component of Atlantic Ocean variability—the Atlantic Multidecadal Oscillation. Through multivariate statistical analysis of an expanded database, we further investigate this hypothesized signal to elucidate propagation dynamics. The Eurasian Arctic Shelf-Sea Region, where sea ice is uniquely exposed to open ocean in the Northern Hemisphere, emerges as a strong contender for generating and sustaining propagation of the hemispheric signal. Ocean-ice-atmosphere coupling spawns a sequence of positive and negative feedbacks that convey persistence and quasi-oscillatory features to the signal. Further stabilizing the system are anomalies of co-varying Pacific-centered atmospheric circulations. Indirectly related to dynamics in the Eurasian Arctic, these anomalies appear to negatively feed back onto the Atlantic's freshwater balance. Earth's rotational rate and other proxies encode traces of this signal as it makes its way across the Northern Hemisphere.*

One of the reasons the paper got the attention of the climate science community was the presentation of the possible years at which cycles start again in the future. The dominant (Atlantic Multidecadal Oscillation-based) component of the stadium wave is the upward pointing "pie slice" in the "the wheel" illustration of the Wyatt and Curry (2013) Figure 13, which I've included here as my Figure 3.17-2. I've highlighted in yellow the expected "peak year" of the dominant component. It's shown as "2036?" in parentheses.

Figure 13 from Wyatt and Curry (2013)
With Possible "Peak Year" of Dominant Metric Highlighted

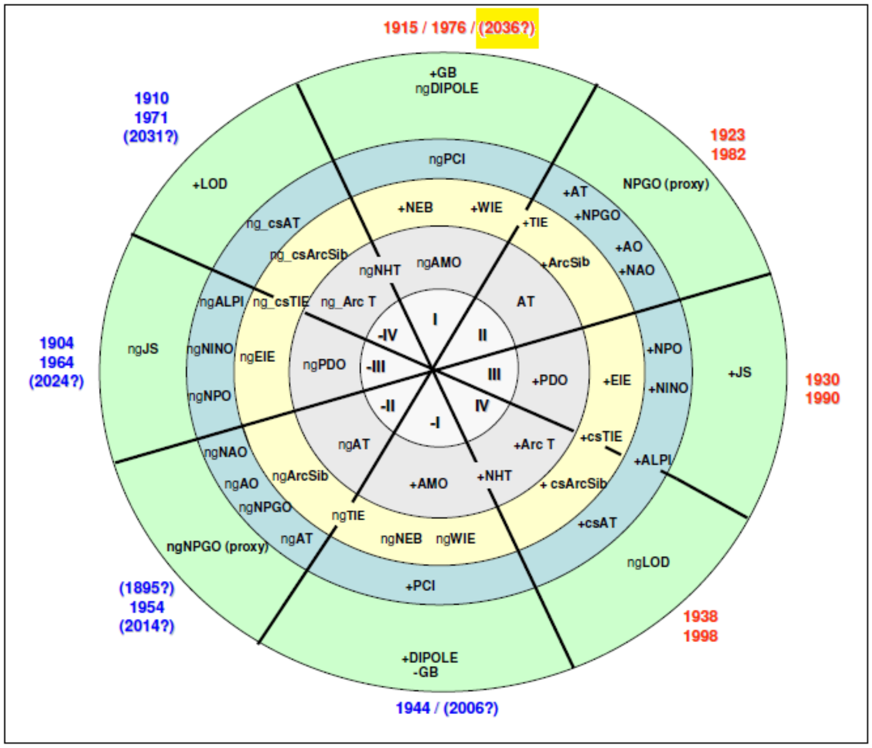


Fig. 13. Stadium-Wave 'Wheel': Temporal Group indices are displayed in 'wheel' segments. Rings contain indices according to system: WKT indices are in the grey ring; ice indices fill the yellow ring; wind and wind-related indices, the blue-green ring; and proxies populate the outer green ring. Refer to text on how to read 'the wheel'.

Figure 3.17-2

This suggests to the authors that the present hiatus (slowdown) in global surface warming could continue until the mid-2030s. This is noted in the press release from the Georgia Institute of Technology ['Stadium Waves' Could Explain Lull In Global Warming](). It includes:

> *The stadium wave periodically enhances or dampens the trend of long-term rising temperatures, which may explain the recent hiatus in rising global surface temperatures.*
>
> *"The stadium wave signal predicts that the current pause in global warming could extend into the 2030s," said Wyatt, an independent scientist after having earned her Ph.D. from the University of Colorado in 2012.*
>
> *Curry added, "This prediction is in contrast to the recently released IPCC AR5 Report that projects an imminent resumption of the warming, likely to be in the range of a 0.3 to 0.7 degree Celsius rise in global mean surface temperature*

> *from 2016 to 2035." Curry is the chair of the School of Earth and Atmospheric Sciences at the Georgia Institute of Technology.*

That, of course, was not well received by the advocates of human-induced global warming.

I've quoted Dr. Judith Curry numerous times in this book. As you'll recall, she is Professor and Chair of the School of Earth and Atmospheric Sciences at the Georgia Institute of Technology. Dr. Curry also hosts the very-popular climate-related blog ClimateEtc. See her post The stadium wave for a further discussion. The thread contains almost 1200 comments. The authors of the paper did a great job of answering questions and responding to comments. To help manage your search for their comments on the thread, Dr. Curry blogs with the name curryja and Marcia Glaze Watt uses Marcia Wyatt.

3.18 – Ocean Phenomenon – 1976 Pacific Climate Shift

While studying climate change, you'll find references to the Pacific Climate Shift in 1976. The shift is also said to take place between 1976 and 1977, when looking at annual data. The Pacific Climate Shift can be seen in many metrics. As a result, it means different things to different people. So let's discuss how the Pacific Climate Shift appears in those different metrics.

PACIFIC DECADAL OSCILLATION

For those studying the abstract sea surface temperature index derived from the data of the extratropical North Pacific called the Pacific Decadal Oscillation, the Pacific Climate Shift of 1976 refers to the time when Pacific Decadal Oscillation Index switched from negative ("cool") to positive ("warm") phases. See Figure 3.18-1 for the Pacific Decadal Oscillation Index data (from JISAO here), with the data smoothed with a 61-month (basically a 5-year) filter.

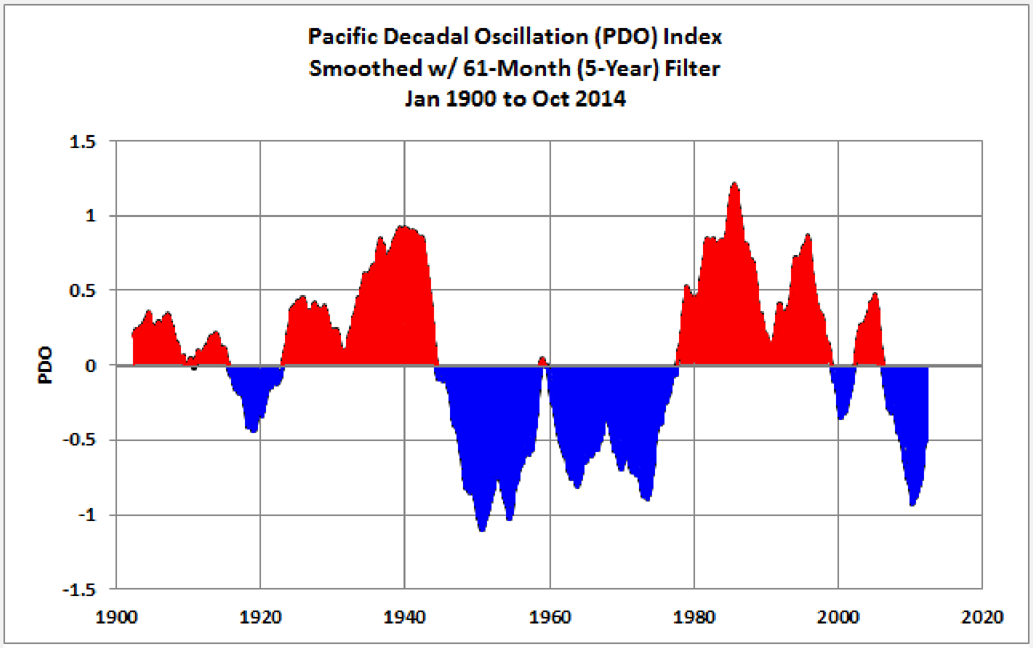


Figure 3.18-1

Due to the smoothing, the transition from negative to positive Pacific Decadal Oscillation Index value doesn't occur at 1976 in Figure 3.18-1. However, if we look at the data in monthly format, no smoothing, as shown in Figure 3.18-2, then the shift occurs in 1976.

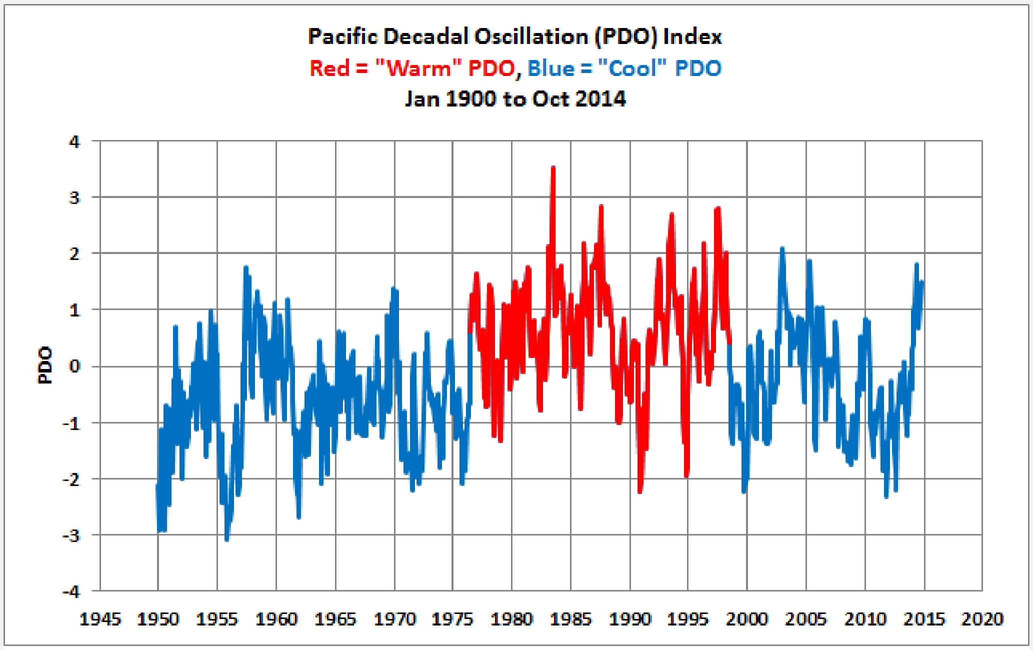


Figure 3.18-2

Present thinking is that the Pacific Decadal Oscillation switched back to the negative mode in 1998 or 1999. That transition would be, primarily, in response to the transition from the 1997/98 El Niño to the 1998-01 La Niña. There was also some thought that the Pacific Decadal Oscillation may have switched back to the positive mode in 2014 in response to The Blob, but it's way too soon to tell if it's a long-term shift.

EL NIÑO-SOUTHERN OSCILLATION

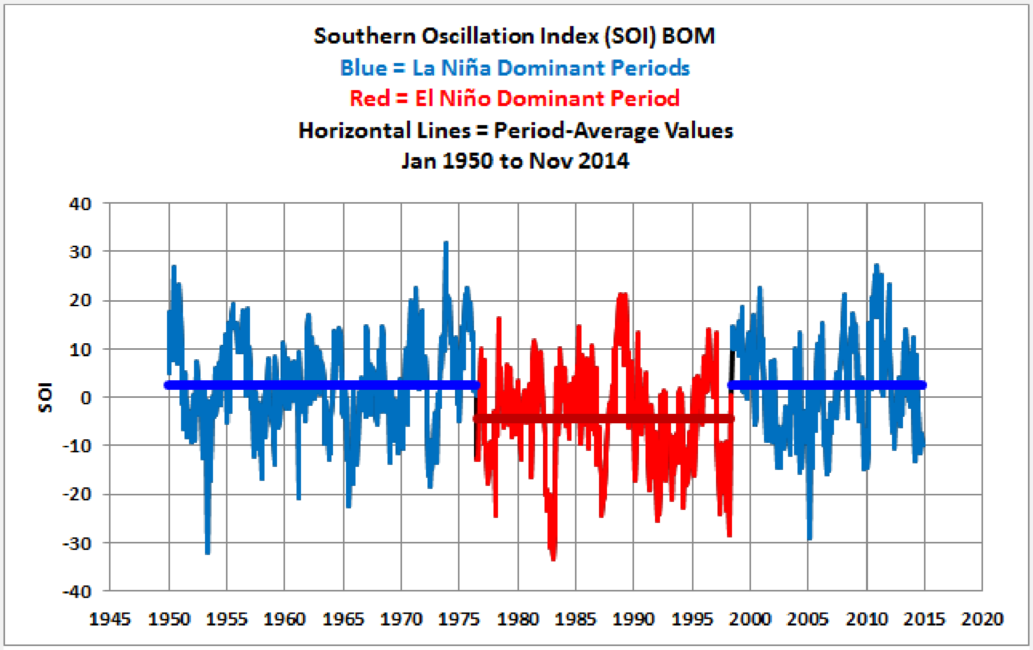


Figure 3.18-3

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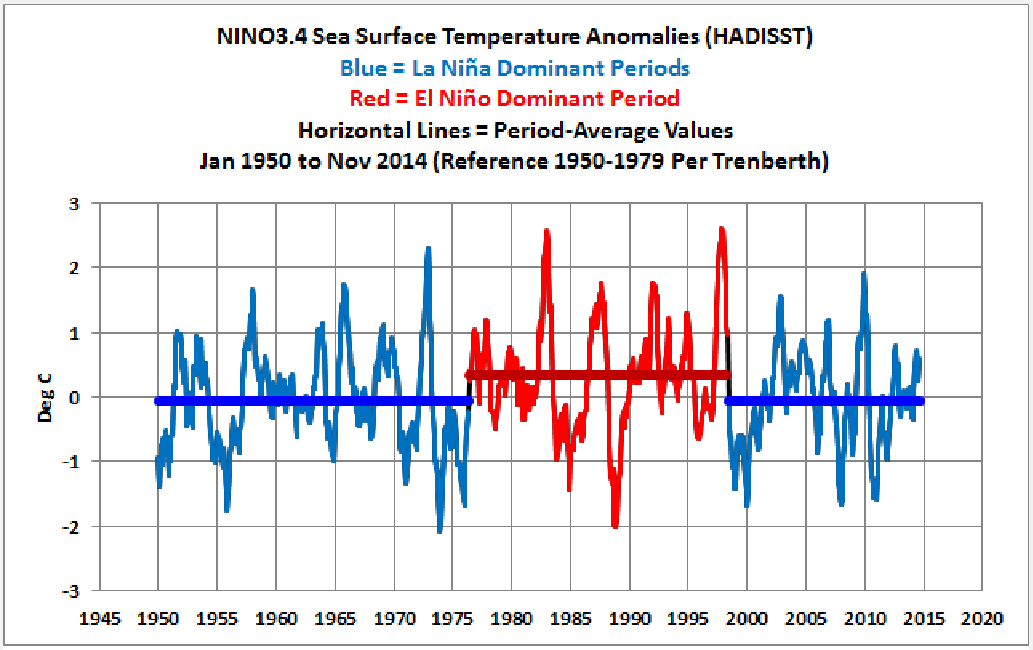


Figure 3.18-4

For researchers studying El Niño-Southern Oscillation (ENSO), the 1976 Pacific Climate Shift also refers to a shift in the dominance of La Niña events to El Niño events at that time. Refer to the Southern Oscillation Index data in Figure 3.18-3 and the sea surface temperature anomalies for the NINO3.4 region in Figure 3.18-4. Using the base years of 1950 to 1979 recommended by Trenberth (1999) The Definition of El Niño, the periods before and after the El Niño dominance show that La Niñas dominated but only by a very small amount. It could be said that there was a very small bias to La Niña and the conditions were basically ENSO-neutral. In both, I've included period-average values to highlight the shifts in dominance. Also note the shift back to La Niña dominance (or shift back to ENSO neutral conditions for the sea surface temperature-based index) after the start of the 1998-01 La Niña.

EAST PACIFIC SEA SURFACE TEMPERATURES

It is difficult to find this phenomenon discussed in scientific studies. It too occurred in 1976. For this discussion, we're looking at the sea surface temperature data for the East Pacific Ocean, from pole to pole (90S-90N, 180-80W). That portion of the Pacific stretches from the dateline in the west to Panama in the east, and we're looking at coordinates that include portions of the Arctic and Southern Oceans, too. This is not a small portion of the oceans. It covers about 33% of the surface of the global oceans. In Figure 3.18-5, I've highlighted the sea surface temperature anomalies before the shift (from 1950 to 1976) in blue, and the data after the shift, through 2013, in red. I've also presented the period-average sea surface temperature anomaly values for the before and after periods as horizontal lines.

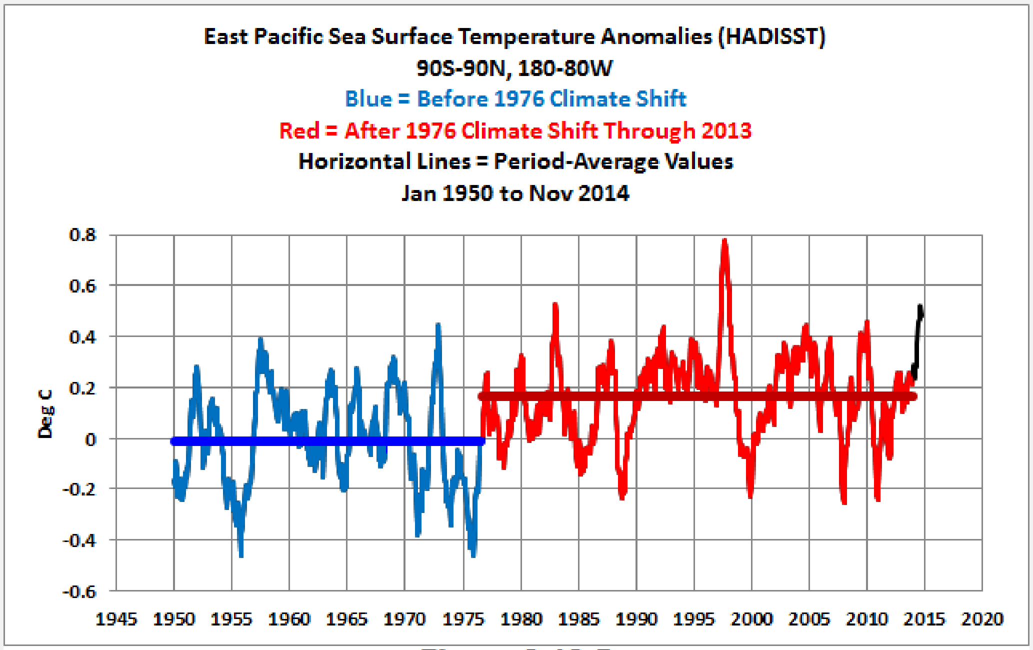


Figure 3.18-5

It's pretty obvious that in 1976 the sea surface temperatures for the entire East Pacific Ocean from pole to pole shifted upwards about 0.17 deg C (0.3 deg F). Also note the shift in the low points of the dips in sea surface temperatures in response to the La Niña events. Before the shift, the downward spikes reached to about -0.4 deg C (-0.72 deg F), but after the shift they could only reach to the neighborhood of -0.2 deg C (-0.36 deg F) during La Niñas. I've excluded the 2014 data because there may have been another shift in 2014 in response to The Blob, though it will be at least a decade before we can hope to confirm that.

CLOSING NOTE

It's remarkable that much of the warming from 1950 to present for the East Pacific Ocean—a region that covers 33% of the surface of the global oceans or about 23% of the surface of the entire globe—depends on the events that took place in less than one year.

The surface temperatures of 23% of the globe shifted upwards by about 0.17 deg C (0.3 deg F) in 1976/77. As a result, global surface temperatures shifted upwards about 0.04 deg C (about 0.07 deg F) solely from the upward shift in the East Pacific. But the upward shift in East Pacific would also have contributed to the warming of land surface air temperatures because much of the warming of land surface air temperatures is in response to the warming of ocean surfaces. (Again see Compo and Sardeshmukh (2009) **Oceanic influences on recent continental warming**.)

Recall the graph of surface temperature from the Introduction (Figure Intro-19) that showed the Trenberth "big jumps" in global surface temperatures. I've included it again as Figure 3.18-6. The impacts of the 1976 Pacific Climate shift contributed to it. The Atlantic Multidecadal Oscillation also switched to its warming phase about that time. Of course, as discussed in Chapter 3.7, the additional upward steps were responses to the 1986/87/88 an 1997/98 El Niño events.

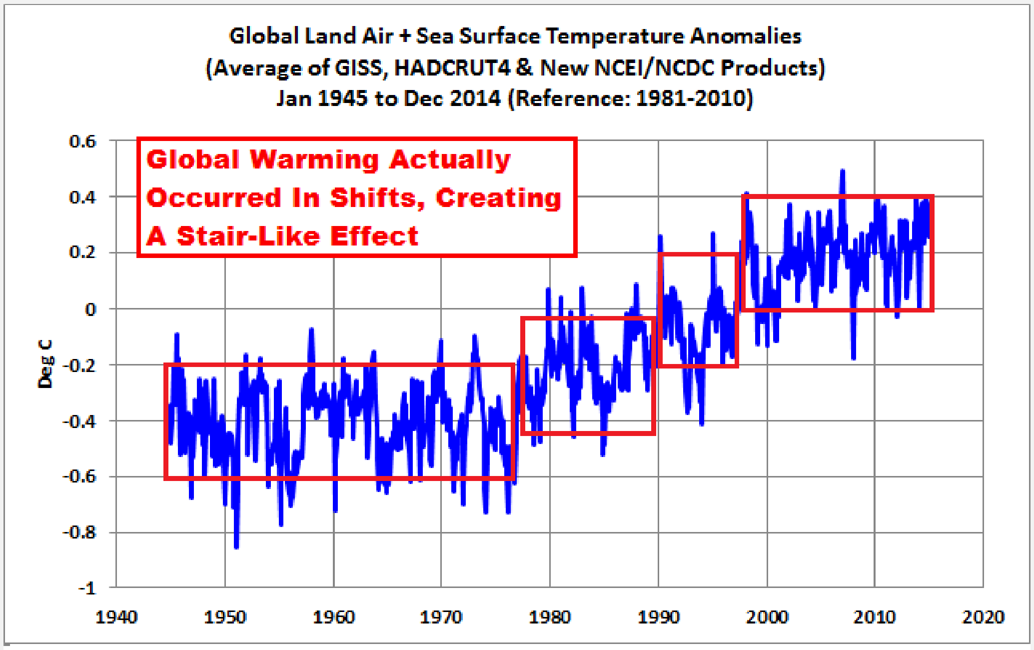


Figure 3.18-6

ADDITIONAL READING ABOUT THE 1976 CLIMATE SHIFT

There are a number of papers that discuss the causes and impacts of the 1976 Climate Shift, including:

- Giese et al. (2002) The Southern Hemisphere Origins of the 1976 Climate Shift
- Wang and An (2001) Why the Properties of El Niño Changed During the Late 1970s
- Guilderson and Shrag (1998) Abrupt Shift in Subsurface Temperatures in the Tropical Pacific Associated with Changes in El Niño

3.19 – Natural Forcing: Solar Radiation

It might be hard to believe, but the variations in the output of the sun and the impacts of those variations are other sources of debate. We'll present an overview of them in this chapter. I will not, however, discuss the physics behind those variations. And I will also not discuss the many theories about how the variations in the Sun's output might impact climate. That in itself would require another book. What this chapter does present is the differences in scientific opinion about how the Sun's output has varied over the long-term and in recent decades. And, once again, we'll present the most-important sun-related metric of all: downward shortwave radiation at the surface.

Keep in mind that the Sun is the primary source of energy that drives climate on Earth and there is ongoing research into how much the Sun's output has varied with time. The differences in the estimated long-term and short-term variations are quite large as you shall see.

THE SOLAR CYCLE

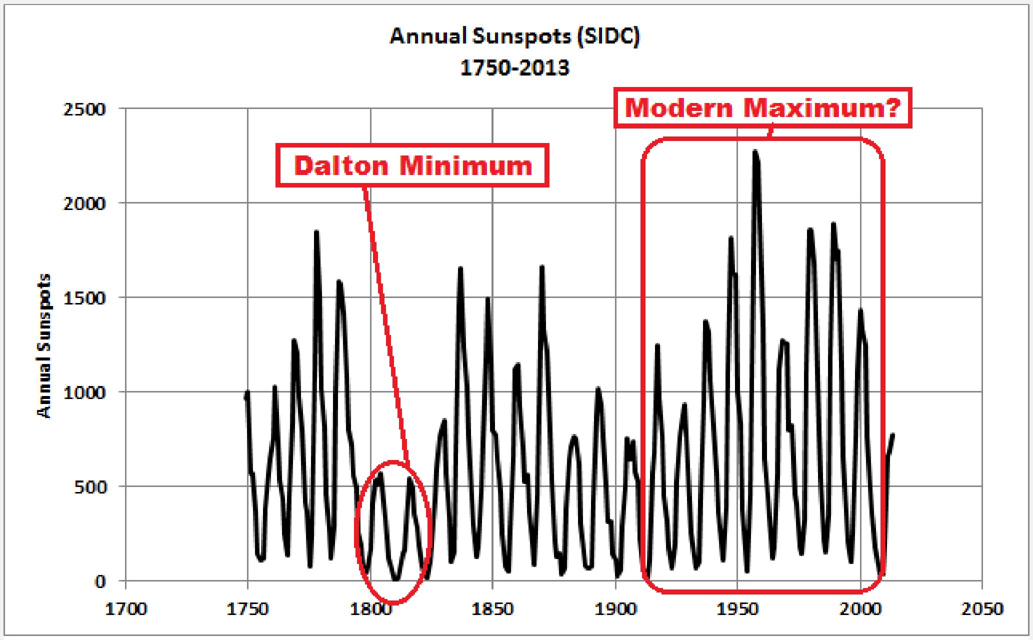


Figure 3.19-1

Many centuries ago, scientists began recording the number of sunspots visible from Earth. They discovered variations in the number of sunspots, called the solar cycle, with a cycle length averaging about 11 years. See the discussion of [the sunspot cycle] at the NASA Marshall Space Flight Center website. There is an even easier-to-understand introduction at the What is the solar cycle? webpage at the geared-for-kids NASA StarChild website.

Figure 3.19-1 above illustrates the annual observer-counted sunspots from the year 1750 to 2013. The sunspot data are from the Solar Influences Data Center (SIDC), and they are available to download at the Monthly climate indices webpage at the KNMI Climate Explorer.

Scientists have numbered the solar cycles. Solar Cycle 1 began in 1755 and ended in 1766. As of 2015, we're in the midst of Solar Cycle 24, which began in 2008.

The 11-year solar cycles are very obvious in Figure 3.19-1, as are the additional variations in the number of sunspots during those cycles. I've highlighted with a red circle the period of unusually low sunspots known as the Dalton Minimum, roughly from 1790 to 1830. Also note how there has been relatively high sunspot counts starting around 1914 with Solar Cycle 15, also highlighted in red. That has led the period from Solar Cycle 15 to the end of Solar Cycle 23 in the 2000s to be called the Modern Maximum.

There is research, however, leading to the conclusion that the Modern Maximum is caused by changes in how sunspots were counted, not from an actual increase in solar activity…in general, that sunspots were over-counted since the 1940s, and prior to 1885 they were undercounted. See Clette et al. (2014) Revisiting the Sunspot Number. The full paper is here, and an overview of the paper can be found in the corresponding Clette et al. (2014) presentation here. In looking at the graph on page 3 of that presentation (included as my Figure 3.19-2), there are no grand maxima.

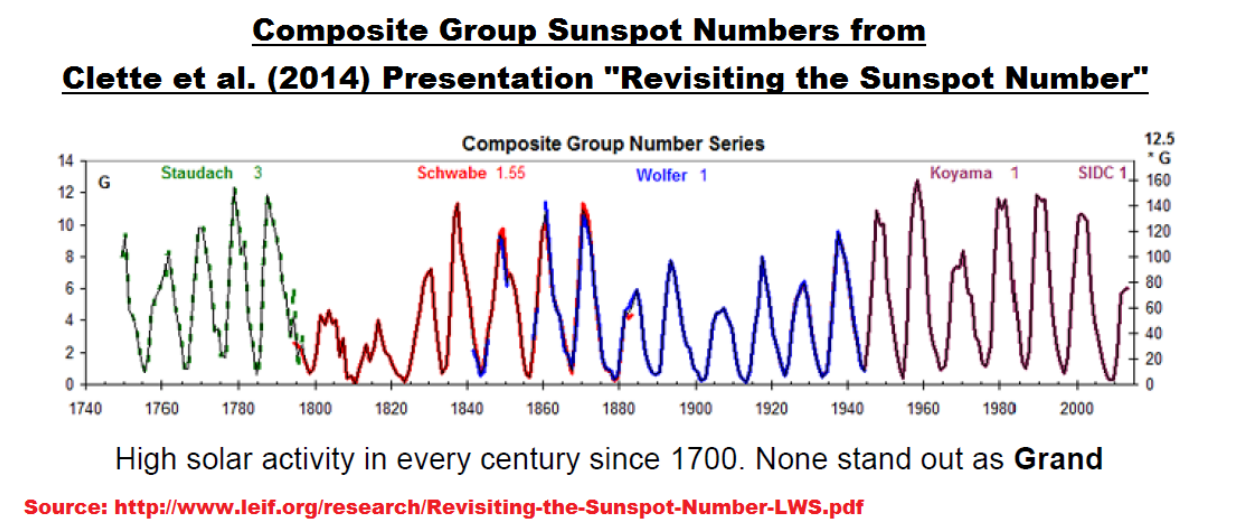


Figure 3.19-2

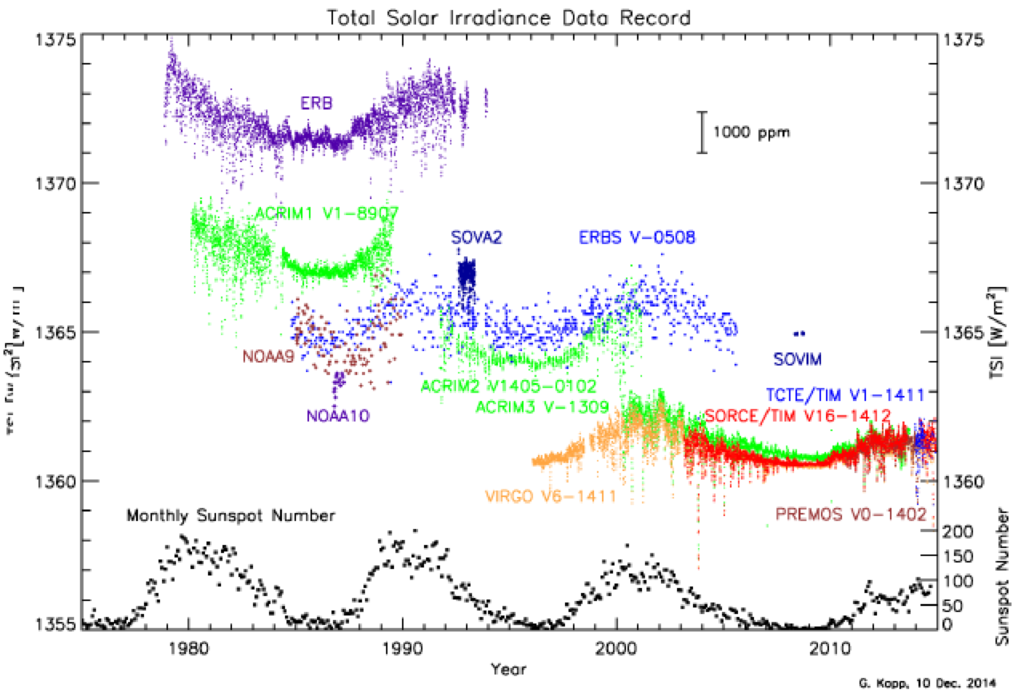
The new "official" sunspot data are planned to be released in 2015.

TOTAL SOLAR IRRADIANCE

Total Solar Irradiance (TSI) is the sum of the Sun's radiation, at all wavelengths, received at the Top of the Atmosphere (TOA). It is, however, put into terms relating to the surface area of the Earth. That is, it is presented in units of watts per square meter (watts/m^2).

Numerous satellites have been used to measure the total solar irradiance (at the top of the atmosphere) starting in the late 1970s. Unfortunately, the sensors in each satellite are calibrated differently. See Figure 3.19-3, which includes the measured total solar irradiance from the array of different satellites over the years. That graph is from Greg Kopp's research webpage at the University of Colorado website. It refers to the Kopp and Lean (2011) paper A New, Lower Value of Total Solar Irradiance: Evidence and Climate Significance.

TSI Climate Data Record (University of Colorado)



Source: http://spot.colorado.edu/~koppg/TSI/index.html#TSI_data_record

Figure 3.19-3

Because there is no single satellite record, the data need to be merged to produce a continuous record. Because of the satellite calibrations, there are different results based on how the satellite data are merged. More on that in a little while.

Using sunspot numbers and a various other proxies, scientists have endeavored to reconstruct the long-term record of total solar irradiance. Six of those reconstructions are shown in Figure 3.19-4. The data for that graph are available through Dr. Leif Svalgaard's research webpage here. Dr. Svalgaard, solar physicist at Stanford University, has included the data in a spreadsheet here. The data are all normalized to 1366 watts/m^2 for the period of 1980 to 2000, which is why the data all align staring at the solar maximum of solar cycle 21. Note how wide the spread becomes prior to the 1940s.

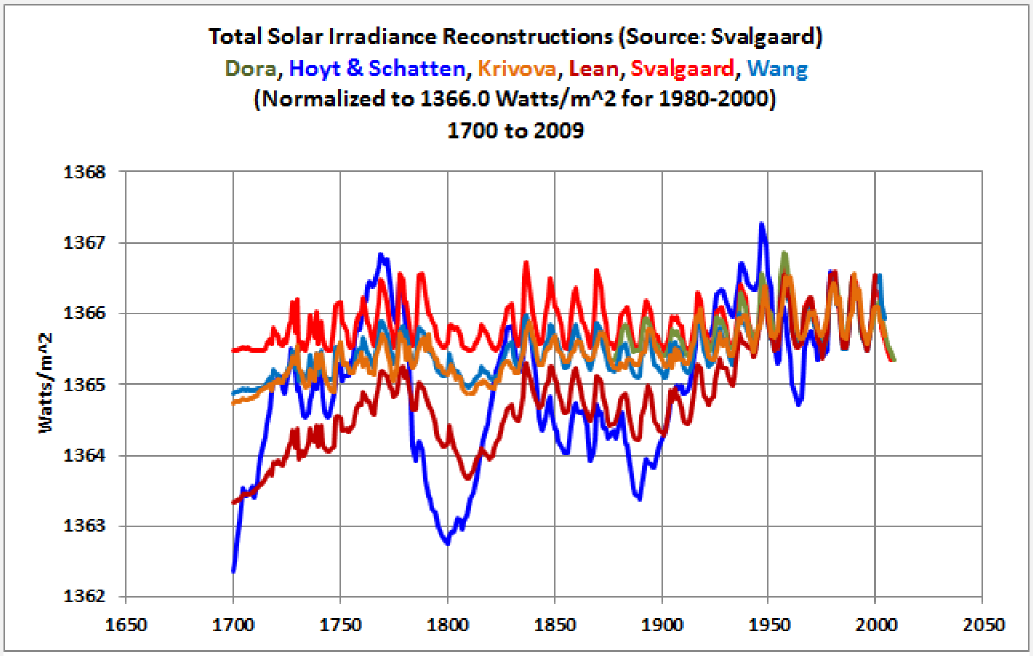


Figure 3.19-4

I've shortened the time period by starting the total solar irradiance reconstructions at 1880 in Figure 3.19-5. I've also limited the number of reconstructions to those by Hoyt and Schatten, Lean, and Svalgaard. With the rise in total solar irradiance from the 1880s to about 1950, the Lean reconstruction and the Hoyt and Schatten reconstruction would help climate modelers produce the early warming during the first half of the 20th Century. Climate modelers did, in fact, use those two reconstructions, among others, for input to their models. (See Table S9.1 from the IPCC AR4 Supplementary Material here.) Modelers continued to use the Lean reconstruction for the models in the IPCC's 5th Assessment Report. (See the SolarisHeppa discussion here.) This is why it is often said that the Sun contributed to the warming from the mid-1910s to about 1945 and that it could not have contributed to the warming from the mid-1970s to present.

Now take a closer look at the Svalgaard reconstruction (red curve). The solar minimums remain relatively constant, all reaching roughly 1365.5 watts/m^2. If the Svalgaard reconstruction is correct, then the warming that took place in the early 20th

Century was also not caused by an increase in the output of the Sun…at least not to the extent of the other two.

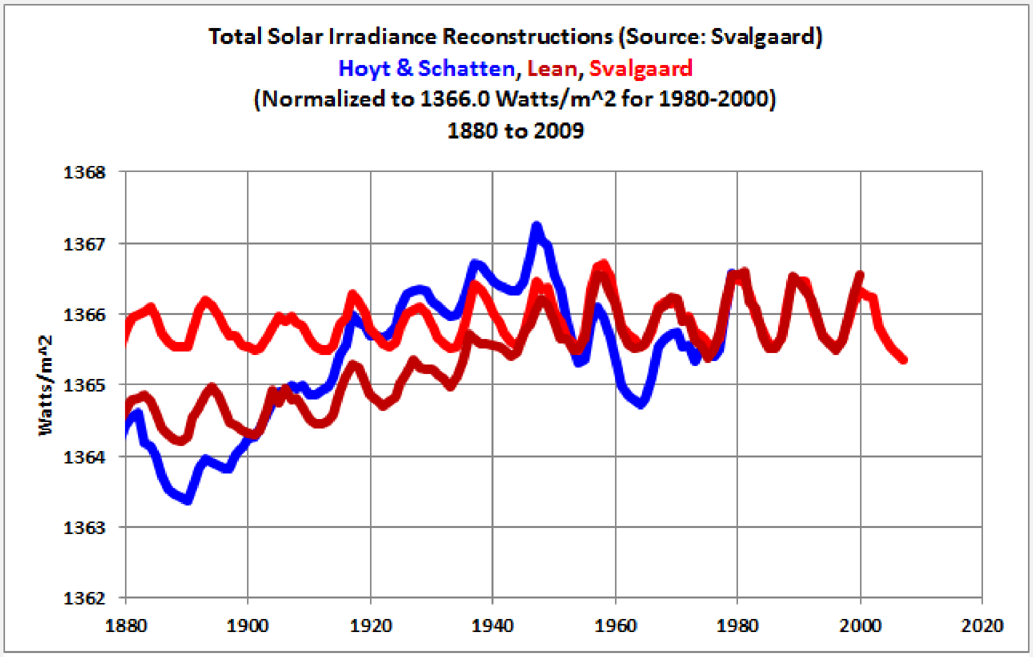


Figure 3.19-5

But as we showed in Figure 1.17-16, global surfaces warmed about 3-times faster during the 30-year period ending in 1945 than was hindcast by climate models. Without that boost from the Lean reconstruction, that model failing would be even greater.

SATELLITE-BASED TOTAL SOLAR IRRADIANCE DATA

As noted during our discussion of Figure 3.19-3 above, because there is not a continuous single satellite record, data from the different satellites must be merged to reconstruct total solar irradiance during the satellite era. And because of the wide range of satellite calibrations, there are different results based on how the satellite data are merged.

Figure 3.19-6 illustrates the annual total solar irradiance from 1980 to January-October 2013 from two sources. The data in maroon are from the Active Cavity Radiometer Irradiance Monitor (ACRIM) website. See the ACRIM data webpage, specifically the ACRIM Composite TSI Results (1979-2013). The data in blue are from Physikalisch-Meteorologisches Observatorium Davos (PMOD). The PMOD data are available at the KNMI Climate Explorer, through their Monthly climate indices webpage. PMOD discuss their dataset at their Solar Constant webpage, while the ACRIM dataset is discussed at their Composite Time Series webpage.

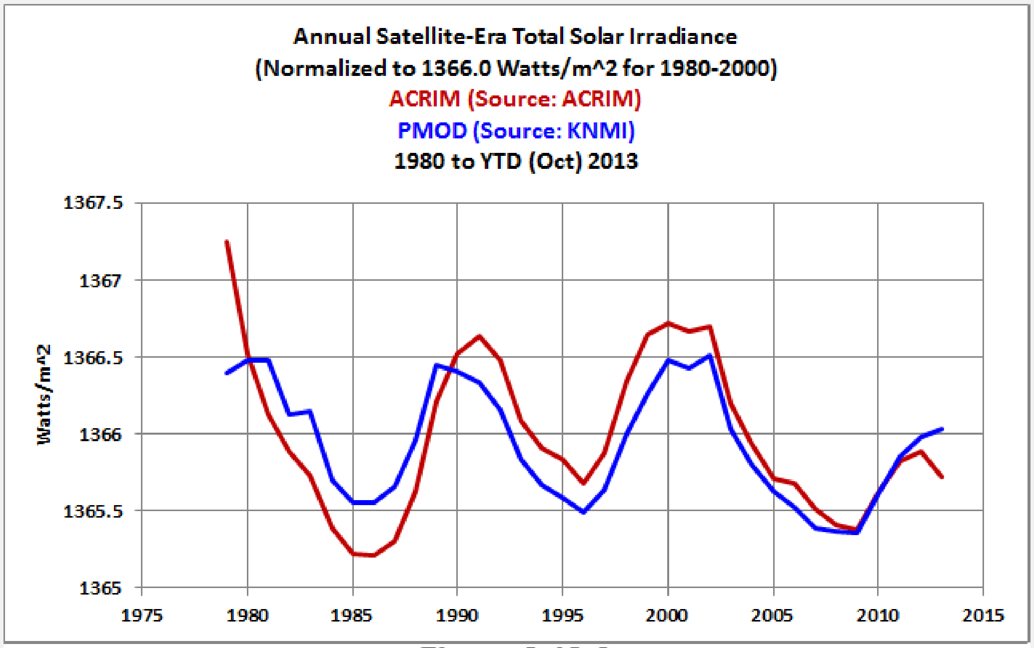


Figure 3.19-6

There are obvious differences between the ACRIM and PMOD composites, in both the heights of the solar maximums of the first three cycles (Solar Cycles 21 to 23), but also in the depths of the solar minimums between them. There is an obvious agreement, though, on the fact that the maximum of Solar Cycle 24 is well below the other three. That agrees with the Sunspot data. Refer back to Figure 3.19-2. The debates between the ACRIM and PMOD scientists have been going on for years. Refer to the discussions on the respective websites.

HOW MUCH OF AN EFFECT DOES THE SOLAR CYCLE HAVE ON GLOBAL SURFACE TEMPERATURES?

For this discussion, we'll refer to the GISS Global Temperature Trends: 2007 Summation webpage. There, under the heading of *Solar Variability*, GISS writes:

> *Several analyses have extracted empirical global temperature variations of amplitude about 0.1°C associated with the 10-11 year solar cycle, a magnitude consistent with climate model simulations, but this signal is difficult to disentangle from other causes of global temperature change, including unforced chaotic fluctuations.*

BUT TOTAL SOLAR IRRADIANCE IS MEASURED AT THE TOP OF THE ATMOSPHERE…

How much sunlight actually reaches the Earth's surface? The total solar irradiance at the top of the atmosphere is about 1366 watts/m^2. That value is known as the "solar constant"…which, depending on your point of view, isn't very constant. But the sun only shines on one side of the planet at a time, and due to spherical shape of the Earth, and due to clouds and aerosols (both natural and man-made) reflecting sunlight back to space, much less reaches the surface (averaged over day and night). And as we've shown earlier a number of times, according to the output of the NCEP-DOE Reanalysis-2, Figure 3.19-7, the sunlight reaching Earth's surface (known as downward shortwave radiation at the surface) is about 187 watts/m^2.

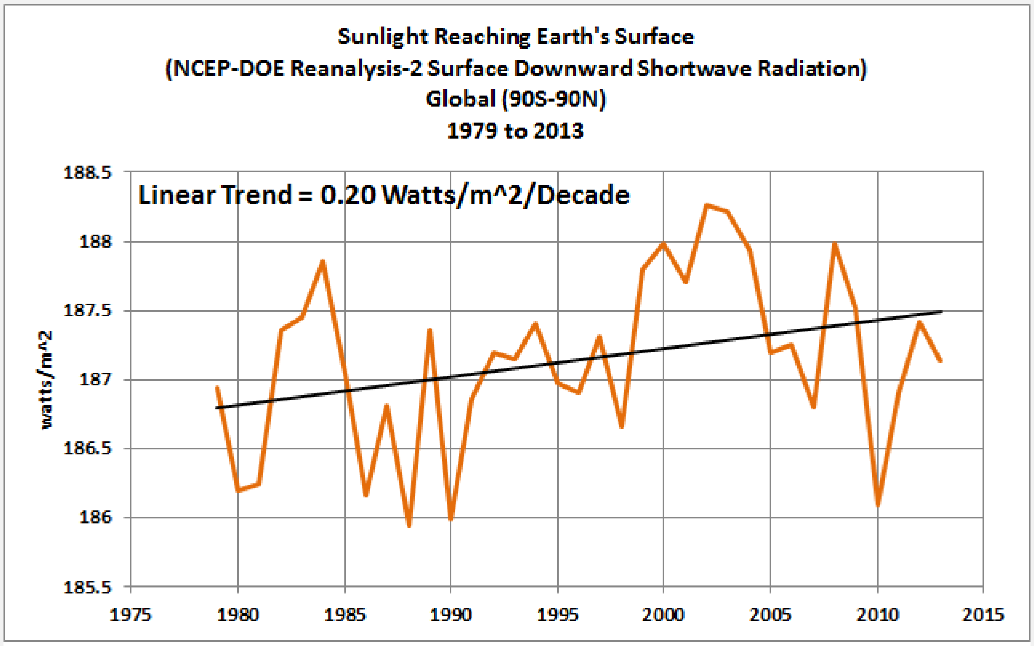


Figure 3.19-7

The NCEP-DOE Reanalysis-2 was introduced in the Kanamitsu et al. (2002) paper NCEP–DOE AMIP-II Reanalysis (R-2).

Note also that the sunlight reaching Earth's surface has increased at a rate of about 0.2 watts/m^2 from 1979 to 2013, according to the NCEP-DOE Reanalysis-2. That casts tremendous amount of doubt on the assumption that only the increase in infrared radiation associated with anthropogenic greenhouse gases could have caused the warming of the Earth's surface, and, more importantly, the warming of the Earth's oceans to depth. Again, it must be remembered that sunlight can penetrate and warm the oceans to depths of 200 meters (though most is absorbed in the top 10 meters). On the other hand, downward longwave radiation (infrared radiation), which is associated with man-made greenhouse gases, can only penetrate the top few millimeters of the ocean surface. As a result of that disparity in ocean penetration, if infrared radiation and sunlight were to increase equal amounts, the warming effects of the sunlight on the oceans would be many orders of magnitude greater than that of infrared radiation.

According to the NOAA Annual Greenhouse Gas Index, the total radiative forcing attributable to man-made greenhouse gases increased from 1.7 watts/meter^2 in 1979 to 2.9 watts/meter^2 in 2013, or a rise in infrared radiation of 1.2 watts/meter^2 from 1979 to 2013. And referring to Figure 3.19-7, the amount of sunlight reaching into the oceans increased about 0.7 watts/meter^2 in that time. If the NCEP-DOE Reanalysis-2 is correct, the sunlight-caused warming of the oceans dwarfed the infrared radiation-caused warming…again due to sunlight's much greater ability to penetrate and warm the oceans.

NOTE: I've noted the following numerous times throughout this book where I've used the graph in Figure 3.19-7. It is one of the few graphs in this book that you would not be able to easily verify with online source materials. In 2014, NOAA began renovating their National Model Archive and Distribution System (NOMADS). As part of those changes, NOAA (temporarily?) removed the NCEP-DOE reanalysis from NOMADS. Many of the metrics supplied by NOAA from the NCEP-DOE reanalysis had been (past tense) also available through the KNMI Climate Explorer, but KNMI also removed that NCEP-DOE reanalysis from their website. The outputs of that reanalysis are no longer available anywhere to the public, as far as I know, in an easy-to-use format.

3.20 – Natural Forcing: Volcanic Aerosols

Explosive volcanic eruptions can spew ash and sulfur aerosols into the stratosphere, depending on their magnitude. Both ash and sulfur aerosols would block sunlight and cause a temporary cooling of the Earth's surface, but which has the greater impact, ash or aerosols?

In the 1980s, scientists determined that sulfur aerosols, not the ash, were responsible for the measureable effects of explosive volcanic eruptions on global surface temperatures. The ash particles only spent a few months in the stratosphere before they fell back to Earth's surface, while the sulfate aerosols stayed longer, blocking sunlight for a few years and causing a temporary drop in global surface temperatures. There is a general overview of these effects, along with links to the scientific studies, in the U.S. Geological Survey (USGS) webpage Volcanic Sulfur Aerosols Affect Climate and the Earth's Ozone Layer.

AEROSOL OPTICAL THICKNESS DATA

One of the most commonly used climate-related indices of volcanic aerosols is the Stratospheric Aerosol Optical Thickness data from the Goddard Institute of Space Studies (GISS). It is based on the 1993 paper by Sato et al. Stratospheric aerosol optical depths, 1850-1990. There were no satellite observations available for this metric before the late 1970s data so the long-term data are a mix of different measurement types. Sato et al. write:

> *We divide our discussion of stratospheric aerosol data sources into four periods (Figure 1), which have successively improved data quality. In period 1 (1850-1882) we have only very crude estimates of, aerosol optical thickness based on the volume of ejecta from major known volcanoes, supported by qualitative reports of atmospheric optical phenomena. Period 2 (1883-1959) has measurements of solar extinction, but during the time of principal volcanic activity (1883-1915) the data are confined to middle-latitude northern hemisphere observatories. Period 3 (1960-1978) has more widespread measurements of solar and stellar extinction, lunar eclipses, and some in situ sampling of aerosol properties. Period 4 (1979-1990) adds precise widespread data from satellite measurements.*

My Figure 3.20-1 is Figure 1 from Sato et al. (1993). They have also listed a number of catastrophic, explosive volcanic eruptions on it.

Figure 1 from Sato et al. 1993

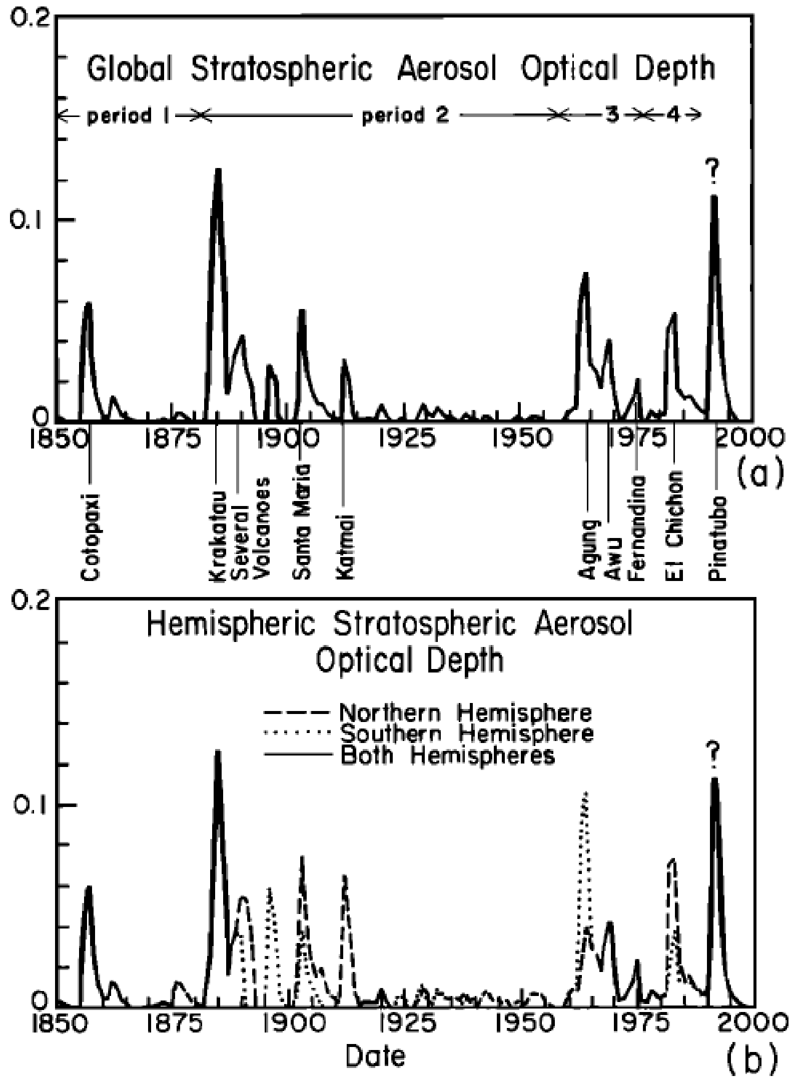


Fig. 1. Estimated stratospheric aerosol optical depth at $\lambda = 0.55$ μm: (*a*) global mean and (*b*) hemispheric means.

Figure 3.20-1

GISS has since revised their estimates. See their notes on the GISS Stratospheric Aerosol Optical Thickness data webpage.

Figure 3.20-2 presents the global and hemispheric GISS stratospheric aerosol optical depth data, which is presently available here from January 1850 to September 2012. You'll note how some volcanos have greater impacts on the Northern Hemisphere than the Southern, and vice versa. Example: Note how the eruption of Katmai in 1912 had no impact on the Southern Hemisphere. Katmai is in Alaska, at the high latitudes of the Northern Hemisphere, so its aerosols would not be carried to the Southern Hemisphere. According to the Alaska Volcano Observatory webpage Katmai 1912 Eruption Centennial, Katmai was the "world's largest volcanic eruption of the 20th Century", yet it has much less of an impact on aerosol optical depth in the Northern Hemisphere and globally than El Chichon (Southern Mexico) in 1982 and Mount Pinatubo (Philippines) in 1991, both of which are located in the tropics of the Northern Hemisphere.

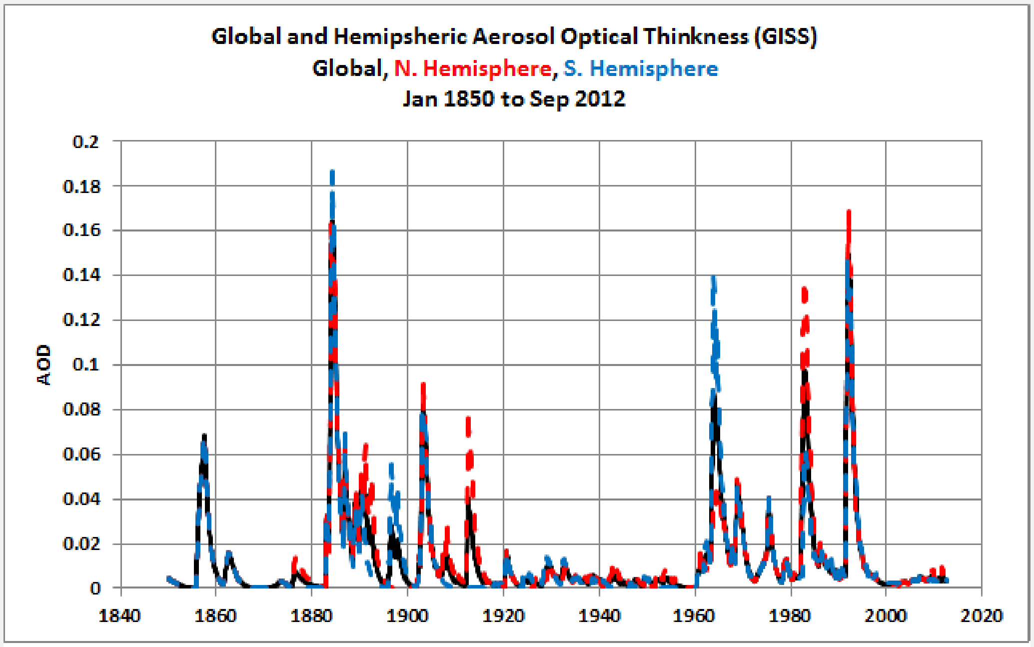


Figure 3.20-2

Figure 3.20-3 below presents the global aerosol optical depth data, full term, along with the linear trend. As you'll note, the linear trend is flat, suggesting (1) that the eruptions in the early portion of the instrument temperature record were comparable to those in the latter part and (2) that the aerosols from explosive volcanic eruptions had no long-term impact on global surface temperatures.

But notice the period between the mid-1910s and 1960. Volcanic aerosols dropped considerably during that period; that is, there were no catastrophic explosive volcanic eruptions then. More sunlight than "normal" should have been reaching the Earth's surface at that time. That additional sunlight, according to some theories, caused the gradual surface warming during that period. Unfortunately, starting in the mid-1940s, surface temperature data show the warming of Earth's surfaces first slowed, then reversed and cooled, in some parts of the globe until the mid-1970s.

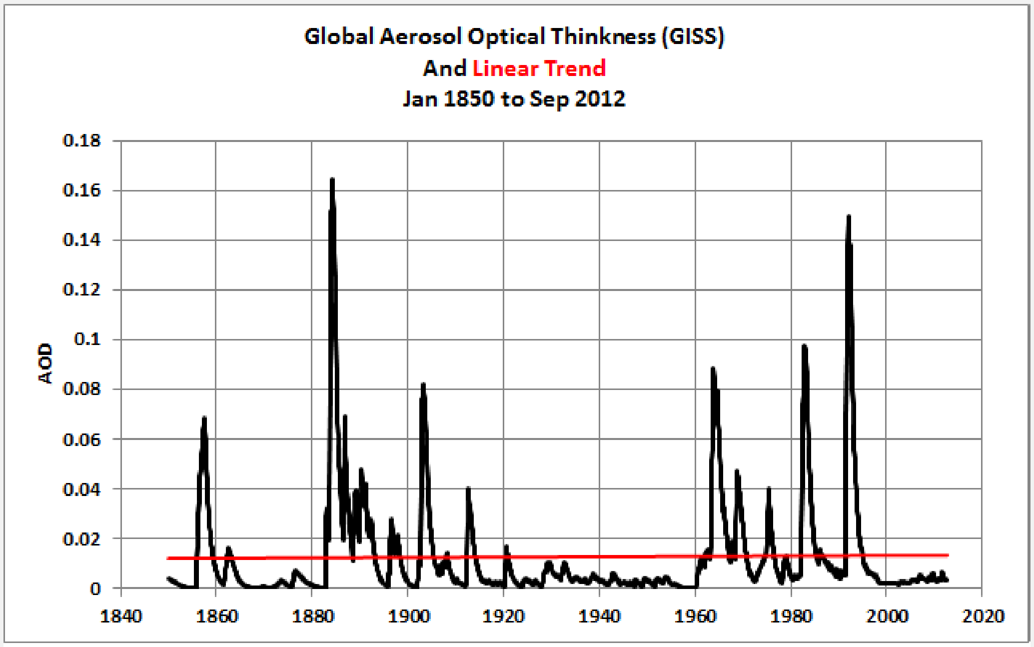


Figure 3.20-3

VOLCANIC AEROSOLS CAN IMPACT TRENDS OVER MULTIDECADAL TIME PERIODS

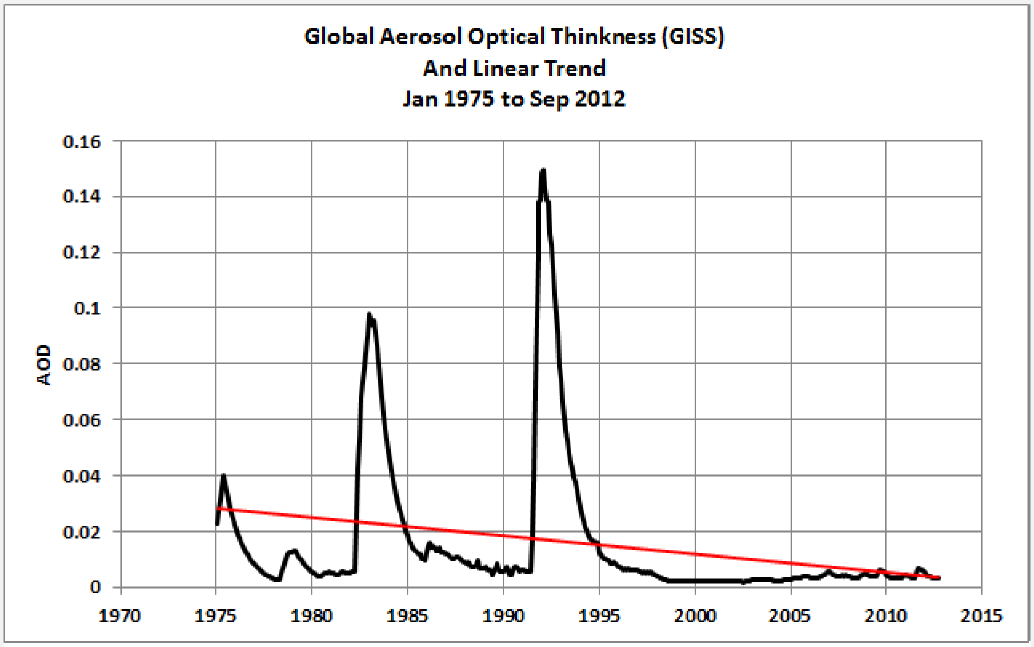


Figure 3.20-4

We noted how the aerosol optical depth data show no long-term trend, but that doesn't mean volcanic aerosols did not have an impact on multidecadal time periods.

The recent warming period is typically said to start in the mid-1970s, most often at 1975. So we'll use that as the start year for this discussion.   Figure 3.20-4 presents the GISS aerosol optical depth data from January 1975 to September 2012 (the last month of data available at this time). The eruptions of Mexico's El Chichon in 1982 and Mount Pinatubo in the Philippines in 1991 occurred in the first half of that period. As a result, the aerosol optical depth data have a negative trend. That means volcanic aerosols cooled the globe during the first half of this period, but not the second, which means they enhanced the warming trend since 1975.

Aerosol optical depth data and global surface temperatures are compared in Figure 3.20-5. In response to the eruption of Mount Pinatubo in 1991, there was a noticeable drop in global surface temperatures, along with the rebound a few years later. That makes sense. But there was a seemingly illogical upward spike in surface temperatures during the eruption of El Chichon in 1982. This inconsistency, of course, leads to debates about the impacts of volcanic aerosols on surface temperatures.

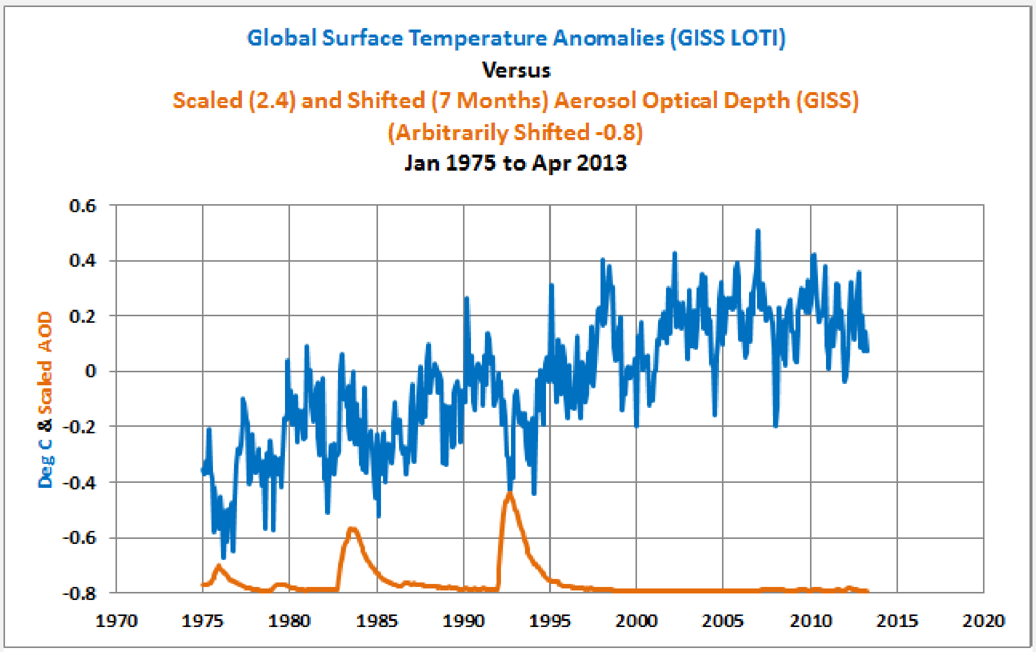


Figure 3.20-5

But there is a logical reason for the upward spike in 1982, and it's the 1982/83 El Niño, which was a strong East Pacific El Niño that rivaled the strength of the 1997/98 super El Niño. That 1982/83 El Niño more than counteracted the effects of the volcanic aerosols from El Chichon. On the other hand, there was also an El Niño event when Mount Pinatubo erupted in 1991, but it was a weaker Central Pacific El Niño and its impacts on global surface temperatures were overwhelmed by the aerosols from Mount Pinatubo.

NOTE: For Figures 3.20-5 above and Figure 3.20-6 below, the scaling factor and time delay for the aerosol optical depth data are based on the results of the 2011 Foster and Rahmstorf paper Global temperature evolution 1979–2010 for the GISS old data. That is, I have not presented the updated GISS data (based on the NOAA/NCEI ERSST.v4 pause-buster data) in those graphs. The interim GISS global surface temperature data were downloaded from the KNMI Climate Explorer. [End note.]

We can used the GISS aerosol optical depth data, altered by the scaling factor and time lag mentioned in the note, to approximate the impacts of the volcanic aerosols on global surface temperatures…and linear trends. See Figure 3.20-6.

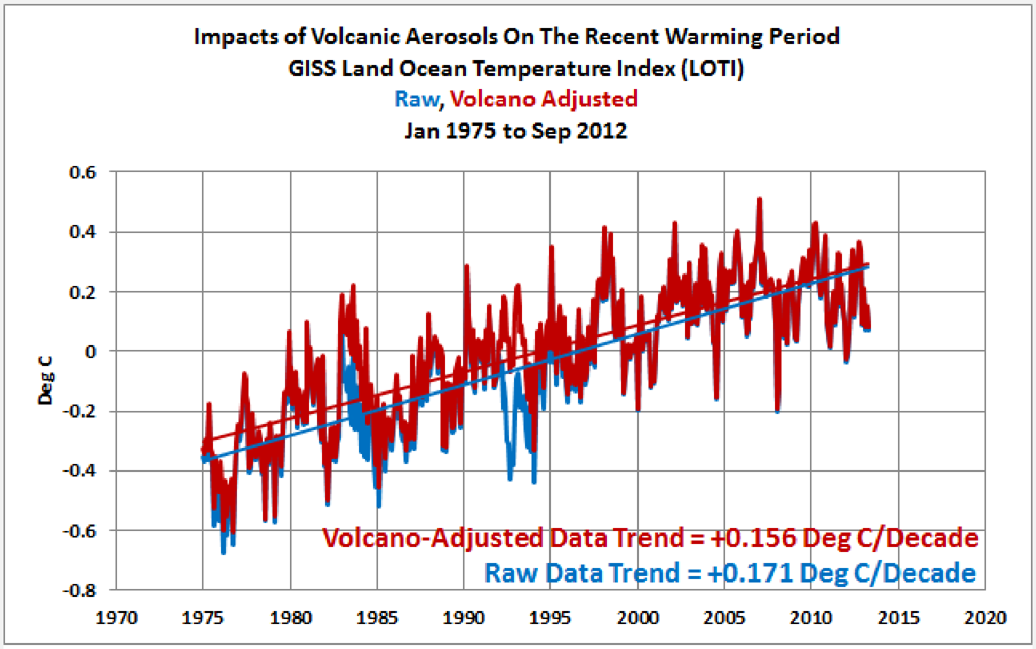


Figure 3.20-6

You'll note how the volcano-adjusted global surface temperature data have a slightly lower trend than the raw data, about 0.015 deg C/decade. You might be wondering why I would spend the time to discuss such a small difference. There is about a 0.03 deg C/decade difference in the warming rates of the early warming period (1914 to 1945) and the late warming period (1975 to 2014), with the recent warming period warming at the faster rate. So some of that additional warming during the late warming period was caused by the timing of those volcanic eruptions.

CONFIRMING THAT VOLCANIC AEROSOLS DO CAUSE COOLING AT THE SURFACE

Earlier in Chapter 3.7 – Ocean Mode: El Niño and La Niña, we detrended the satellite-era sea surface temperature data for the South Atlantic, Indian and West Pacific oceans and for the North Atlantic. Then we compared those two subsets to the sea surface temperatures of the NINO3.4 region of the equatorial Pacific, where the NINO3.4 data were scaled to account for the different responses to ENSO and lagged to account for the time delays in the responses to ENSO outside of the tropical Pacific. I've included those comparisons again as Figures 3.20-7 and 3.20-8.

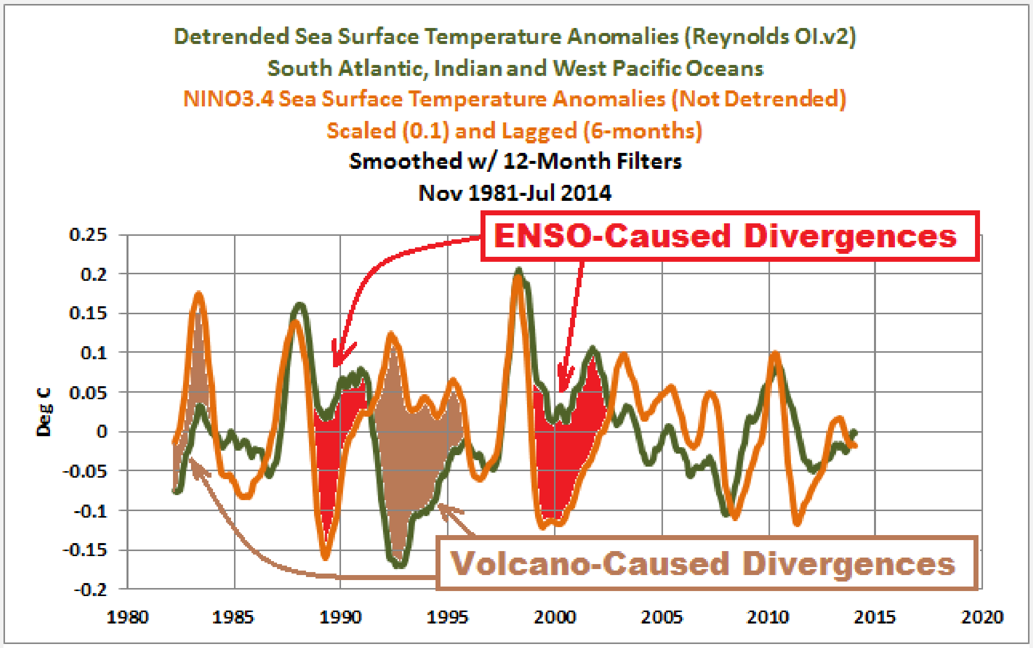


Figure 3.20-7

# # #

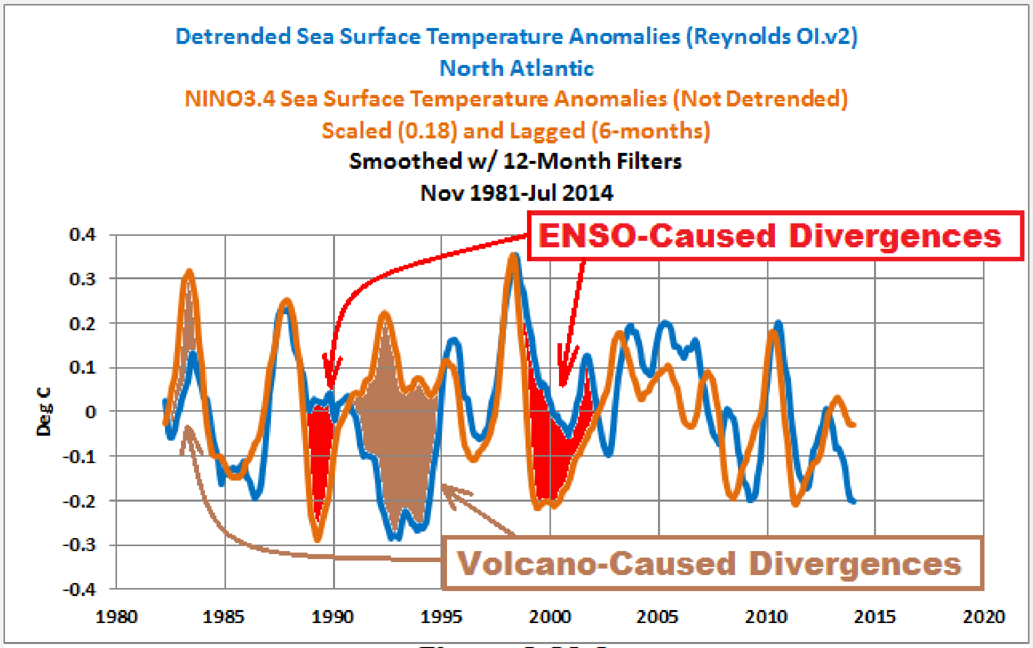


Figure 3.20-8

The intent of that exercise was to show how surface temperatures did not cool proportionally during the La Niñas that followed the strong El Niño events of 1986/87/88 and 1997/98. But as shown, we can also use them to show that surface temperatures were impacted by the eruptions of El Chichon in 1982 and Mount Pinatubo in 1991. Surface temperatures should have warmed more in response to the 1982/83 El Niño, but the eruption of El Chichon reduced the impacts of that El Niño on sea surface temperatures around the globe. And the impacts on sea surface temperatures of the eruption of Mount Pinatubo in 1991 stands out quite plainly with the dip and rebound.

VOLCANIC AEROSOLS FROM TROPICAL VOLCANOS CAN ALSO CAUSE WARMING OF THE NORTHERN HEMISPHERE LAND SURFACES DURING THE WINTER

This discussion sounds counterintuitive, but research has shown that volcanic aerosols from explosive volcanos in the tropics can cause land surfaces to warm during the winter in the Northern Hemisphere. These findings were presented in the 2000 paper by Alan Robock Volcanic Eruptions and Climate. The abstract reads in part:

> *Large volcanic eruptions inject sulfur gases into the stratosphere, which convert to sulfate aerosols with an e-folding residence time of about 1 year. Large ash particles fall out much quicker. The radiative and chemical effects of this aerosol cloud produce responses in the climate system. By scattering some solar radiation back to space, the aerosols cool the surface, but by absorbing both solar and terrestrial radiation, the aerosol layer heats the stratosphere. For a tropical eruption this heating is larger in the tropics than in the high latitudes, producing an enhanced pole-to-equator temperature gradient, especially in winter. In the Northern Hemisphere winter this enhanced gradient produces a stronger polar vortex, and this stronger jet stream produces a characteristic stationary wave pattern of tropospheric circulation, resulting in winter warming of Northern Hemisphere continents. This indirect advective effect on temperature is stronger than the radiative cooling effect that dominates at lower latitudes and in the summer.*

That counterintuitive warming is a very important response to volcanic aerosols, and climate models do not simulate it.

CLIMATE MODELS DO NOT PROPERLY SIMULATE THE ATMOSPHERIC RESPONSES TO VOLCANOS IN THE TROPICS

Climate models even do a poor job of simulating how explosive volcanic eruptions in the tropics impact atmospheric circulation of the Northern Hemisphere. These failings are discussed in Driscoll, et al. (2012) Coupled Model Intercomparison Project Phase 5 (CMIP5) Simulations of Climate Following Volcanic Eruptions.

The abstract of Driscoll, et al. (2012) reads (my boldface):

> *The ability of the climate models submitted to the Coupled Model Intercomparison Project 5 (CMIP5) database to simulate the Northern*

> *Hemisphere winter climate following a large tropical volcanic eruption is assessed. When sulfate aerosols are produced by volcanic injections into the tropical stratosphere and spread by the stratospheric circulation, it not only causes globally averaged tropospheric cooling but also a localized heating in the lower stratosphere, which can cause major dynamical feedbacks. Observations show a lower stratospheric and surface response during the following one or two Northern Hemisphere (NH) winters, that resembles the positive phase of the North Atlantic Oscillation (NAO). Simulations from 13 CMIP5 models that represent tropical eruptions in the 19th and 20th century are examined, focusing on the large-scale regional impacts associated with the large-scale circulation during the NH winter season.* ***The models generally fail to capture the NH dynamical response following eruptions.*** *They do not sufficiently simulate the observed post-volcanic strengthened NH polar vortex, positive NAO, or NH Eurasian warming pattern, and they tend to overestimate the cooling in the tropical troposphere. The findings are confirmed by a superposed epoch analysis of the NAO index for each model.* ***The study confirms previous similar evaluations and raises concern for the ability of current climate models to simulate the response of a major mode of global circulation variability to external forcings.*** *This is also of concern for the accuracy of geoengineering modeling studies that assess the atmospheric response to stratosphere-injected particles.*

According to Driscoll, et al. (2012), there are fundamental flaws in the response of atmospheric circulation in climate models to large changes in external forcings.

MANY CLIMATE MODELS USED BY THE IPCC NEGLECTED VOLCANIC AEROSOLS AS LATE AS THE 4th ASSESSMENT REPORT IN 2007

Back in *Chapter 2.1 – Basic Overview of Climate Models* we noted how the IPCC was misleading readers with their depictions of when features were added to climate models. One example was that they showed volcanos being considered as early as 1995 in their 2nd Assessment Report. We discussed how that was misleading because many of the modeling groups hadn't bothered to include volcanic aerosols among their climate model forcings as late as the IPCC's 4th Assessment Report in 2007.

Table 3.6 from Rind et al. (2009)

Table 3.6. Forcings used in IPCC AR4 simulations of 20th century climate change. This Table is adapted from SAP 1.1 Table 5.2 (compiled using information provided by the participating modeling centers, see http://www-pcmdi.llnl.gov/ipcc/model_documentation/ipcc_model_documentation.php) plus additional information from that website. Eleven different forcings are listed: well-mixed greenhouse gases (G), tropospheric and stratospheric ozone (O), sulfate aerosol direct (SD) and indirect effects (S), black carbon (BC) and organic carbon aerosols (OC), mineral dust (MD), sea salt (SS), land use/land cover (LU), solar irradiance (SO), and volcanic aerosols (V). Check mark denotes inclusion of a specific forcing. As used here, "inclusion" means specification of a time-varying forcing, with changes on interannual and longer timescales.

	MODEL	COUNTRY	G	O	SD	SI	BC	OC	MD	SS	LU	SO	V
1	BCC-CM1	China	√	√	√								
2	BCCR-BCM2.0	Norway	√		√				√	√			
3	CCSM3	USA	√	√	√		√	√				√	√
4	CGCM3.1(T47)	Canada	√		√								
5	CGCM3.1(T63)	Canada	√		√								
6	CNRM-CM3	France	√	√	√		√						
7	CSIRO-Mk3.0	Australia	√		√								
8	CSIRO-Mk3.5	Australia	√		√								
9	ECHAM5/MPI-OM	Germany	√	√	√	√							
10	ECHO-G	Germany/Korea	√	√	√	√						√	√
11	FGOALS-g1.0	China	√		√								
12	GFDL-CM2.0	USA	√	√	√		√	√			√	√	√
13	GFDL-CM2.1	USA	√	√	√		√	√			√	√	√
14	GISS-AOM	USA	√		√					√			
15	GISS-EH	USA	√	√	√	√	√	√	√	√	√	√	√
16	GISS-ER	USA	√	√	√	√	√	√	√	√	√	√	√
17	INGV-SXG	Italy	√	√	√								
18	INM-CM3.0	Russia	√		√							√	
19	IPSL-CM4	France	√		√	√							
20	MIROC3.2(hires)	Japan	√	√	√		√	√	√	√	√	√	√
21	MIROC3.2(medres)	Japan	√	√	√		√	√	√	√	√	√	√
22	MRI-CGCM2.3.2	Japan	√		√							√	√
23	PCM	USA	√	√	√							√	√
24	UKMO-HadCM3	UK	√	√	√	√							
25	UKMO-HadGEM1	UK	√	√	√	√	√	√			√	√	√

Table 3.20-1

My Table 3.20-1 is Table 3.6 from Rind et al. (2009) Modeling the Effects of Aerosols on Climate. It presents the types of climate forcings used in climate models stored in the CMIP3 archive, which was used by the IPCC for their 4th Assessment Report. In the last column "V", all of the climate models that included volcanic aerosols are indicate by a check mark. Quite remarkably, only 11 of the 25 models included volcanic aerosols…less than half.

To confirm that, Figure 3.20-9 illustrates the ensemble-member averages of the simulations of global surface temperature anomalies from 1880 to 1999 from two climate models: CCMA CGCM3.1 5-member mean and the GISS Model EH 5-member mean. Both are stored in the CMIP3 archive and are available for downloading at the KNMI Climate Explorer, specifically the KNMI Monthly CMIP3+ scenario runs webpage. The CMIP3 models were used by the IPCC in their 4th Assessment Report in 2007.

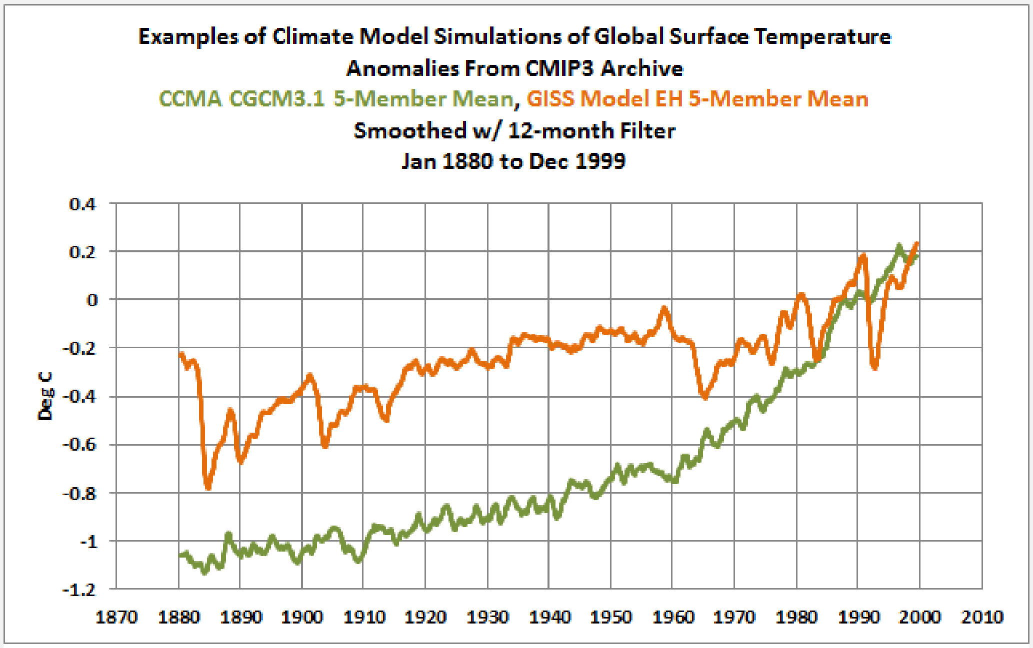


Figure 3.20-9

There are no dips and rebounds associated with volcanic aerosols in the CCMA CGCM3.1 climate model outputs, which, as you can see, grossly overestimate the global warming from 1880 to 2000.

SUMMARY OF VOLCANIC AEROSOLS

Volcanic aerosols can and do temporarily cool the Earth's surface by restricting sunlight. Volcanic aerosols also cause the warming of land surfaces during the winters that trail the explosive eruption. More than half of the climate models used by the IPCC for their 4th Assessment Report excluded volcanic aerosols from their forcings. And those models that included volcanic aerosols in the 5th Assessment Report poorly simulated the atmospheric responses to them.

3.21 – Closing Notes About Naturally Occurring Climate Variability

We discussed a lot of topics in this section and the sheer number of them may have detracted from the processes that contributed to the global warming we've experienced over the past 3+ decades…a warming that climate models attribute to man-made greenhouse gases.

We discussed the Atlantic Multidecadal Oscillation in Chapter 3.3 – Ocean Mode: Atlantic Multidecadal Oscillation, and we showed how the sea surface temperature records indicate that the Atlantic Multidecadal Oscillation contributed substantially to the global warming, primarily in the Northern Hemisphere, since the mid-1970s.

We discussed the coupled ocean-atmosphere processes that drive El Niño and La Niña events in Chapter 3.7 – Ocean Mode: El Niño and La Niña. There we also explained how El Niño and La Niña events act as a chaotic, naturally occurring, sunlight-fueled recharge-discharge oscillator. The ocean heat content data for the tropical Pacific and the satellite-era sea surface temperature records confirm that understanding. And we illustrated and discussed how the satellite-era sea surface temperature records indicate that much of the warming over the past 33 years can be explained as aftereffects of strong El Niño events…which are fueled by sunlight.

In Chapter 3.11, we discussed how data indicate the vast majority of the long-term warming of the Extratropical North Pacific to depths of 700 meters was caused by a shift in the wind patterns there in late 1980s. We also discussed in Chapter 3.7 that the primary cause of the long-term warming of the Tropical Pacific to depths of 700 meters was natural…and depended on short-term blasts of sunlight there in response to 4 La Niña events.

We also discussed the natural warming of the oceans to depth in Chapter 1.15. There we also presented a graph that combined the Extratropical North Pacific Ocean Heat data (0-700 meters) with the data for the Tropical Pacific. See Figure 3.21-1 (which is the same as Figure 1.15-8.) As a reminder, I borrowed that illustration from the post Is Ocean Heat Content Data All It's Stacked Up To Be? where it was Figure 26.

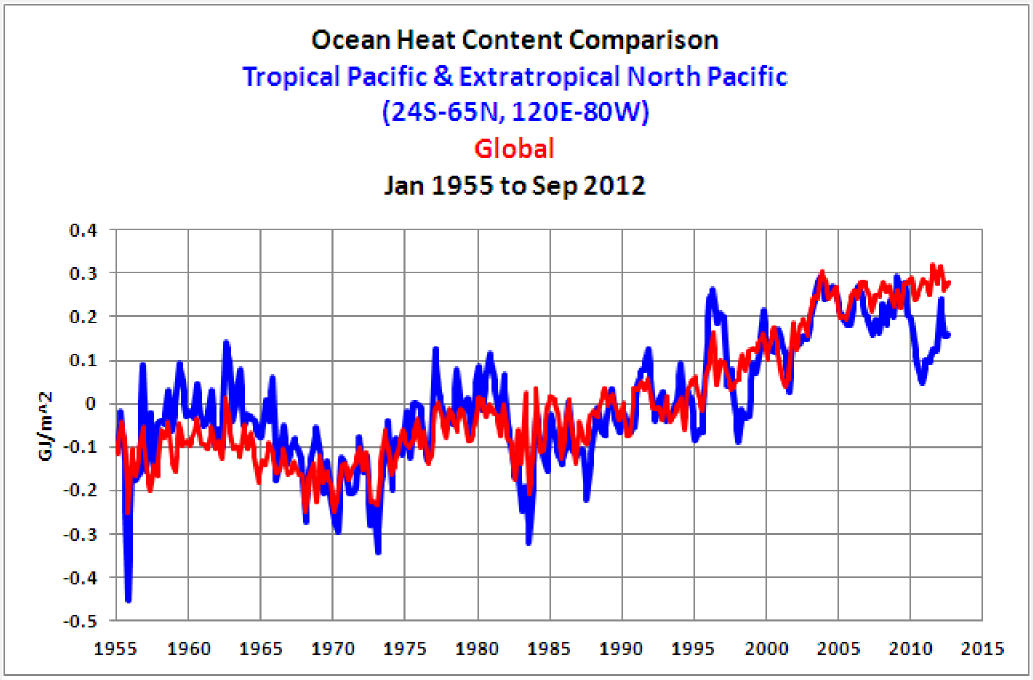


Figure 3.21-1

As I stated in Chapter 1.15, the Tropical Pacific and Extratropical Pacific subsets individually show no evidence of having been warmed from man-made greenhouse gases, but when merged, the global ocean heat content data mimic the long-term warming and the short-term variations of the combination of the Tropical Pacific and Extratropical Pacific subsets. Now consider that the warming of the North Atlantic was also found to have occurred naturally.

Consider a number of things:

Climate model simulations of past and future global warming have changed very little from the first IPCC report back in 1991 to the fifth report in 2013. The modelers have updated the models over the decades, but they still keep coming up with the same basic answers. There's a very basic reason for this: climate models have not been upgraded when new forms of natural variability have been identified.

The Atlantic Multidecadal Oscillation, which contributes to or suppresses global warming primarily in the Northern Hemisphere, was first identified in 1994. (See Schlesinger and Ramankutty (1994) An oscillation in the global climate system of period 65-70 years.) Two decades later, climate models used for attributing global warming to mankind and for future prognostications of global warming do not include the Atlantic Multidecadal Oscillation. We showed in Chapter 3.3 how the Atlantic Multidecadal Oscillation was not a forced component of the climate models stored in the CMIP5 archive and used by the IPCC for their 5th Assessment Report.

The first report I can find that identifies El Niño and La Niña processes as a sunlight-fueled recharge-discharge oscillator is Trenberth et al. (2002) Evolution of El Niño-Southern Oscillation and global atmospheric surface temperatures. Yet the climate models used by the IPCC cannot simulate even the most basic of ENSO-related feedbacks in the tropical Pacific: Bjerknes feedback. Climate modelers basically treat El Niño and La Niña events as noise on a human-induced global warming trend, when data indicate sunlight-fueled El Niño and La Niña-related processes can explain that warming.

There's a simple reason why climate modelers won't include in their models those naturally occurring and naturally fueled processes that contribute to global warming or suppress it. It's a conflict of interest. Plain and simple. If climate models included those naturally occurring and naturally fueled processes, long-term predictions of future global warming could very well drop to the point where politicians realize the moneys they're spending on climate research would be better spent on adaptation.

Someday, hopefully sooner and not later, politicians are going to come to that realization.

CLOSING TO *ON GLOBAL WARMING AND THE ILLUSION OF CONTROL – PART 1*

Thank you for reading *On Global Warming and the Illusion of Control – Part 1*. I hope you learned as much reading it as I did preparing it. We covered many topics about climate science in general, about climate models and about the many modes of natural variability.

Hopefully, as you were reading this ebook, you've come to realize a number of things:

- Climate scientists depend on climate models for the attribution of global warming to man-made greenhouse gases and depend on those models for prognostications of what future climate might be like here on Earth.
- Climate models were created and designed prior to and without an understanding of coupled ocean-atmosphere processes that can contribute to global warming or suppress it. The climate models used by the Intergovernmental Panel on Climate Change and other politics-driven report-writing organizations still do not (cannot) simulate those ocean-atmosphere processes.
- There are coupled ocean-atmosphere processes that can explain the warming of our ocean surfaces during the satellite era and the subsurface warming of our oceans since 1955. Sadly, due to the politics involved with climate change research, few studies of the long-term impacts of those processes have been funded…or will be funded in the future if the current political atmosphere continues.
- Climate models, as noted earlier, are the only means through which the climate science community can attribute to man-made greenhouse gases the global warming we've experienced since pre-industrial times, but the models used in those attribution studies are not capable of simulating the naturally occurring, coupled ocean-atmosphere processes that could also explain that warming.
- Climate models do not properly simulate surface and atmospheric temperatures, ocean heat uptake, precipitation, and sea ice. In other words, they are not yet capable of the tasks for which they assumedly have been designed. Climate models do, however, provide value to discussions of global warming and climate change, inasmuch as they show how poorly they perform at simulating those variables.

Some persons may conclude that climate models were designed and programmed to support United Nations political agendas, not to study climate as it exists on Earth.

As Dr. Richard Lindzen stated in his April, 2014 presentation to the European Institute for Climate and Energy (EIKE):

> *…it should be recognized that the basis for a climate that is highly sensitive to added greenhouse gasses is solely the computer models. The relation of this sensitivity to catastrophe, moreover, does not even emerge from the models, but rather from the fervid imagination of climate activists.*

(See the YouTube video of Dr. Lindzen's presentation here.)

The primary topic for Part 2 of this ebook is climate-related data. But there will likely be topics I've overlooked in Part 1 that you would like to see discussed. I'll try to include those in Part 2 as well.

And as a reminder, this ebook took me almost 2 years to prepare, yet I've given it away, with hope that it will find a much-larger audience than if I had changed a few dollars for it. Please consider throwing a couple of bucks in my tip jar.

Another request: please distribute this book electronically.

Thank you again for reading *On Global Warming and the Illusion of Control – Part 1*.

ABOUT THE AUTHOR

Contrary to the many rumors around the blogosphere, I am one person and my name is Bob Tisdale. I view my role in global warming and climate change debates as that of a science reporter.

As such, I am a regular contributor to WattsUpWithThat, the world's most-visited website about global warming and climate change. I'm probably best known for my well-illustrated data-reliant articles. I also have my own blog Climate Observations, where, in addition to the posts you find at WattsUpWithThat, I also provide monthly updates of global sea surface temperatures and the surface temperatures of the individual ocean basins.

It's difficult not to find one of my graphs, maps or animations when you perform a *Google Image* search about global surface temperatures, sea surface temperatures, ocean heat content, and the like.

I am an independent researcher, a citizen scientist. That is, I receive no funding for my research other than the occasional and much-appreciated donation or tip from generous persons who visit my blog Climate Observations and WattsUpWithThat. In other words, I am not tied to any political agenda. My primary areas of research are (1) the processes that drive naturally occurring ocean-atmosphere processes like El Niño events and their long-term impacts on global climate, and (2) how poorly climate models perform at simulating climate-related metrics. I was recently included in a group of gentlewomen and gentleman scientists in a blog post by Dr. Judith Curry, Professor and Chair of the School of Earth and Atmospheric Sciences at the Georgia Institute of Technology. See Dr. Curry's blog post More Scientific Mavericks Needed.

I have spent years researching data…and then comparing them to the outputs of climate models…so you don't have to. Thank you for allowing me to introduce you to the reasons why many persons are skeptical of the global politics-driven field of climate science, and to show you its realities and its flaws.